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Issued April 24, 1909.

U. S. DEPARTMENT OF AGRICULTURE,

BUREAU OF CHEMISTRY—BULLETIN No. 124.

H. W. WILEY, Chief of Bureau.

CHEMICAL STUDIES OF AMERICAN BARLEYS AND MALTS.

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BY

J. A. LE CLERC,
PHYSIOLOGICAL CHEMIST,

AND

ROBERT WAHL,
SPECIAL AGENT.

WASHINGTON:
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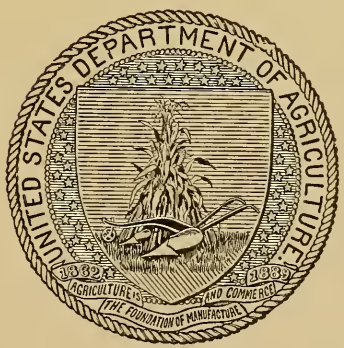

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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Bureau of Chemistry,
Washington, D. C., January 16, 1909.

Sir: I have the honor to submit for your inspection and approval a manuscript containing the preliminary results of investigations specifically authorized by Congress in the agricultural appropriation bill for the fiscal years 1903–1907, to study the barleys grown in different sections of the United States, with a view to improving their quality.

This study is especially valuable at this time, because of the legislation regarding denatured alcohol, for the production of which a certain amount of malt is generally used. The study was made by J. A. Le Clerc, in charge of the vegetable physiological investigations of the Bureau, and Robert Wahl, special agent, with the collaboration of J. S. Chamberlain, T. C. Trescot, A. Given, C. Goodrich, W. J. Young, A. Nilson, N. H. Claussen, and O. Roewade.

I recommend that this report be published as Bulletin No. 124 of the Bureau of Chemistry.

Respectfully,

H. W. Wiley,
Chief of Bureau.

Hon. James Wilson,
Secretary of Agriculture.

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Typical barleys ..... Frontispiece

STUDIES OF AMERICAN BARLEYS AND MALTS.

INTRODUCTION.

During the past decade many investigations have been undertaken regarding the improvement of the quality of barley for both brewing and feeding purposes. The publication of many of these investigations took the form of discussions as to the relative value of a high-protein and low-protein barley for malting, and thereby additional valuable information has been added to our knowledge of the subject.

Moreover, the still more recent legislation regarding denatured alcohol has given additional impetus to the study of barley and malts. It is well known that for the production of alcohol a certain amount of malt is generally used. This malt is added to convert the starch into sugar, which then can be further converted into alcohol by means of yeast through the ordinary process of fermentation. The amount of malt thus used varies from 5 to 15 per cent of the total amount of raw material employed. The efficiency of the malt depends upon the power of converting starch which it possesses; in other words, a malt is more or less valuable for the production of industrial alcohol according to its diastatic power. When it is remembered that for the production of even 100,000,000 gallons of alcohol (that is, 1 gallon per capita) about 10,000,000 bushels of malt will be required, and, further, that malts vary greatly in diastatic power or the power of converting starch into fermentable sugar, then one easily realizes the full importance of a thorough study of American barleys and malts.

It is generally recognized that the chemist and botanist must work together in order to solve the various agricultural problems, and much work has been done regarding the influence of soil, fertilizers, selection of seed, etc., on the quality of the barley produced; the variety, species, or race of barley to be selected for seed; and the effect of climatic conditions on the properties of the crop. As far as possible these data are presented in such a way as to aid the barley grower and at the same time acquaint the consumer with the properties of barleys grown under different conditions. The results of this work are compared with those of other investigators in order to solve some of the questions which relate to the physical and chemical character-

istics of barley. The investigations herein recorded are purely preliminary. It was thought, however, that the results thus far obtained would be of sufficient interest to warrant their publication without waiting for the completion of the work.

REVIEW OF THE LITERATURE.

The view point from which the various investigations on this subject have been conducted and the conclusions drawn will appear from the following survey of the literature.

Protein and its cleavage products are attracting more and more the attention of those who are investigating barley and malt and their products. On the one hand, preference is given to low-protein barley, rejecting as unsuitable for brewing all barleys containing over 11 per cent of protein. Such barley would be best suited for the production of distillers' malt. Other investigators believe that such a line of demarcation is purely arbitrary and is apt during certain seasons to cause the rejection of barleys which may produce good malts and good beer. As a matter of fact, Prior[a] has shown that many Austrian barleys with a protein content of 11 or 12 per cent have furnished superior malts, even for brewing purposes, yielding a high percentage of extract.

The fact that the same variety of barley will vary widely in protein content from year to year, even when grown in the same locality, due to the preponderating influence of environment, would indicate the impracticability of insisting on any such arbitrary standard as the consideration of the protein content alone in accepting or rejecting barley for brewing purposes. Haase, who in 1902 proposed that a good brewing barley should not contain more than 10 per cent of protein, based his conclusions on the fact that Silesian barleys during several years did not average much above 10 per cent. However, in 1905 more than 75 per cent of the barleys examined by Haase contained over 11 per cent of protein. This caused him to adopt 11 per cent as the basis of his system of valuation. This standard refers to the 2-row barley, Hanna and Chevalier, etc., grown in Europe; it does not apply to the ordinary 6-row barleys—the Manchurian or Oderbrucker—grown generally in the Middle Western States, for example, Wisconsin, Minnesota, Iowa, etc., as Wahl has shown.[b] The average protein content of the 6-row barleys grown in this country is nearer 12 than 11 per cent, and only rarely is a sample with less than 11.5 per cent of protein produced. Such a standard may easily be accepted in so far as concerns the 2-row barleys or the thick-skin 6-row barleys—that is, the Bay Brewing barleys, grown principally in Cali-

[a] Wochenschr. Brau., 1905, **22**: 52.

[b] Address at the Vienna International Agricultural Congress, 1907.

fornia—and the thin-skin 6-row Utah Winter barley, for all of these varieties contain on an average about 10.5 per cent of protein.

The literature on barley and malt investigations teems with suggestions relating to the kind of barley best adapted for brewing purposes, the influence of various fertilizers on the composition of barley, the changes it undergoes in the process of malting, the rôle which the extract, or the nitrogen, etc., plays in brewing, and the influence of the various constituents on the quality of the finished product. Comparatively little, however, has been written from the standpoint of the production of industrial alcohol.

Attention should be called to the recent fundamental work of H. T. Brown[a] and his coworkers on the chemistry of barley and malt in their attempt to establish definite relations between the outward characteristics of barley and the chemical and physiological differences as shown by analysis. They likewise studied the methods of estimating the various nitrogenous constituents of both barley and malt, and the migration of these constituents from the endosperm to the embryo during the process of malting. Their results show that after nine days malting 35 per cent of the nitrogenous constituents of the endosperm become soluble and diffusible and are transported to the embryo. These soluble proteins are present in malt and are found in wort in small amounts. They are supposed by some investigators to exert a relatively large influence on the character of the finished product. Brown has divided those soluble and noncoagulable nitrogenous compounds into six classes: Albumoses, peptones, amidamin, ammonia, organic bases, and residual or undetermined protein. On the other hand, Osborne[b] divides the proteins of the whole barley grain, amounting to 10.75 per cent, as follows, with the respective percentage composition given: Leucosin (albumin), 0.3 per cent, equals 2.79 per cent of the total protein; proteose and edestin (globulin), 1.95 per cent, equals 18.14 per cent; hordein, 4 per cent, equals 37.21 per cent; and insoluble protein, 4.5 per cent, equals 41.86 per cent of total protein.

According to Jalowetz[c] the basal end of the barley contains more protein than the distal end, the least amount being found in the middle of the berry. In the ear of the plant the right and left longitudinal halves have the same percentage of protein, whereas the grains on the upper half of the heads are richer in nitrogen than those on the lower half, but the amount of nitrogen per individual berry is constant in all sections of the head; the small berries grown on the less perfectly matured heads of the secondary stalks are richer

[a] Trans. Guinness Res. Lab., 1903, **1** (1): 96–127.

[b] Amer. Chem. J., 1895, **17**: 539.

[c] Zts. gesam. Brauw., 1906, **29**: 172; through Biedermann's Centrbl., 1906, **36**: 229.

in nitrogen than are the well-matured grains found on the main stalks, thus showing that a sample of barley even though coming from a single field and representing one variety may vary much in percentage of protein in individual kernels.

Schjerning [a] has studied the growing barley plant with special reference to the nitrogenous compounds, analyzing the plants at three different stages of their development, namely, at green, yellow, and full ripeness. Beginning with the formation of the grain, at green ripeness, he analyzed the berries up to the full-ripe stage and concluded that "barley has acquired its full maturity when the conversion of the soluble into insoluble carbohydrates and soluble into insoluble proteins has reached its maximum," and that the ripening of barley is a process tending toward a state of equilibrium in respect to its nitrogenous constituents; when properly ripened barley is harvested very little loss due to respiration takes place during storage. Over ripeness is characterized as a loss of substance. He found that on ripening the percentage of soluble nitrogen in the total nitrogen decreased from 45 to 18 and that the amidamin nitrogen decreased from 28 to 5 per cent. Only traces of proteoses and small amounts of peptones were found. He showed that early harvested barley is poorer in protein than the fully matured grain, and that the chemical composition is not influenced by species, variety, or type of barley, but is affected by the character of the soil and climatic conditions. The length of the growing period, cultivation, and climatic conditions influence the nitrogen content also, and therefore the quality of barley can not be determined from the amount of this constituent alone.

This agrees with the researches of Kukla,[b] Jalowetz,[c] Prior,[d] Wahl,[e] and others. These investigators have shown that high protein barleys often give a better malt, which produces a better beer than a malt made from a barley of lower nitrogen content. Kukla also concludes that it is not so much the total protein of barley which influences the quality of the beer as it is the character of the nitrogenous compounds. In his important contribution on the chemistry of barley and malt, Prior [f] has shown that the consideration of the amount of hordein (alcohol-soluble protein) and of the insoluble protein constituents of the endosperm is more important than that of the total protein, which should only be considered when above 13 per cent. The hordein he finds located principally near the embryo,

[a] Compt. rend. travaux lab., Carlsberg, 1906, **6**: 229.

[b] Zts. gesam. Brauw., 1900, **23**: 418.

[c] Ibid., 1906, **29**: 172.

[d] Wochenschr. Brau., 1905, **22**: 52.

[e] Amer. Brew. Rev., 1907, **21**: 274.

[f] Allgem. Zts. Bierbrau. Malzfabr., 1905, **33**: 341, 412; through J. Inst. Brew., 1906, **12**: 159.

extending to about the middle of the kernel; whereas the insoluble protein is found near the periphery of the endosperm. The best barleys for brewing purposes are those containing a medium amount of protein, namely, from 10.5 to 12 per cent. He finds that the hordein and the insoluble proteins rise in general with the total protein.

The increase of protein is always followed by a decrease of one or more of the other constituents of barley. The opposite is also true. The protein substances, from the standpoint of the brewer and maltster, are now being considered as of the utmost importance, and a relation between them and the starch was one of the first to be noted. Haase showed that an increase of protein was followed by a corresponding decrease of starch. This law was based on results obtained, during several years, from Silesian barleys, and appeared to hold good for this variety. As the relation was not found to be true in regard to other barleys, it has been the subject of much controversy.

It is well known that barleys present differences in physical appearance. Some grains show a mealy or floury endosperm, while the endosperm of others is flinty and translucent. The reasons for these differences and the influence which they exert on malting and brewing and the relation between the character of the grain and the protein content have likewise been the subjects of much study. Brown has observed that steely grains can often be converted into the mealy kind; that is, made mellow, through artificial maturation by steeping or even by weathering after harvest. Johannsen[a] long ago showed that the difference between a mealy and a steely or glassy barley was due to the greater number of air spaces in the endosperm of the former, and that in the original condition barleys show no relation between the degree of glassiness and the percentage of nitrogen. In 1868 Jacobsen wrote, in correspondence, that in England it was the general opinion that glassiness and the protein content of barley were related. In 1879 Groenlund wrote an essay in which he showed that early harvested barley can be just as mellow as later harvested barley, and that glassy barley may become mealy by steeping and subsequent drying. He examined 47 different barleys,[b] and concluded that glassy barleys did not always contain more protein than mealy ones, but that very often the opposite is true. Schultze[c] likewise found no relation between glassy kernels and the nitrogen content, but noted that mealy kernels may contain more nitrogen than steely ones. In 1870 Nowacki[d] showed that the difference between a

[a] Compt. rend. travaux lab., Carlsberg, 1884, **2**: 60.

[b] Zts. gesam. Brauw., 1886, **9**: 288.

[c] Ibid., 1881, **4**: 62.

[d] Untersuchungen über das Reifen des Getreides, Halle, 1870.

mealy and a glassy wheat was due to the small air spaces imprisoned between the starch granules of the mealy grains and that the specific gravity of the mealy grains was less than that of the flinty. Munro and Beaven [a] likewise showed that the specific gravity of mealy kernels is less, due to the larger amount of interstitial air, and that the nitrogen content of such grains is lower, in consequence of which they modify better than do the steely grains. Groenlund [b] called attention to the fact that when glassy kernels are steeped and then dried some of the grains become mellow while others remain unchanged. This procedure distinguishes between apparent and real glassiness, and upon this fact Prior [b] bases his method for the determination of the degree of dissolution of barley, which consists of the sum of the mealy grains originally present and the percentage of steely grains which become mealy on steeping. This factor shows that the higher the protein content the lower, as a rule, is the degree of dissolution. A later contribution by Prior [c] called attention for the first time to the rôle played by the variety of barley on this determination; that what was true of one variety was not necessarily so of another; that is, in some varieties the steely grains are more easily modified than in others. H. T. Brown [b] likewise developed a method for the estimation of the coefficient of mealiness, results of which give indication to a certain extent of the value of a barley for brewing or feeding purposes, as he finds that a high coefficient of mealiness is generally accompanied by a low protein content, or vice versa.

Jalowetz [b] investigated the relation between the protein content and the character of the endosperm and agreed with other authors that mealy grains are lower in protein than flinty ones. Instead of soaking or steeping the grains for several days at 45° C. and subsequently drying slowly (Brown's method), he suggests that the grain be treated with 40 per cent formalin at the temperature of a boiling water bath for from twenty to thirty minutes. After washing the grains free from formalin and drying them between filters, the character of the endosperm may be immediately examined. This method is claimed by its author to give a good indication of the value of barley. Beaven [d] shows that the amount of nitrogen and the quality are closely related, and that high nitrogen barley, accompanied by a steely character of the endosperm, has a higher specific gravity, and that twice as much alcohol-soluble protein is found in such barley as in mealy grains. He also intimates that the nitrogen determination is only useful as an index of quality, other things being equal, and

[a] Brown, Trans. Guinness Res. Lab., 1903, **1** (1): 96–127.
[b] Loc. cit.
[c] Wochenschr. Brau., 1905, **22**: 412.
[d] J. Fed. Inst. Brew., 1902, **8**: 542.

that the size of the grain affects the quantity of extract, the large grains giving more extract than small grains of the same protein content. Beaven considers that the specific gravity of barley may afford a fair index as to quality, and that generally the specific gravity decreases as maturation increases.

Somewhat later Harz [a] declared that glassiness of barley is not due to the larger protein content, but to certain kinds of protein substances and to the mechanical combination with the rest of the substances forming the cell. Prior [b] separated the different kinds of proteins and determined their relation to one another and their influence on the mellowness of the barley. He found that the causes of the apparent glassiness are the water-soluble nitrogen-free and nitrogen-containing constituents of the endosperm, constituents which are colloidal in character and which cement the starch-containing cells firmly together. When these apparently steely barleys are steeped the cementing constituents dissolve. The real glassiness is due to the cementing of the starch-containing cells by means of the hordein and the insoluble protein. In collaboration with Hermann, Prior [c] found that when a 100 per cent steely barley was steeped first in 50 per cent alcohol and then in 75 per cent alcohol at 45° to 50° C., and subsequently dried, the steely barleys became altogether mealy. Previous steeping in water was not necessary. Baker and Hulton [d] have recently corroborated Prior's work regarding the fact that permanently or temporarily glassy grains depend upon the presence of nitrogenous or nonnitrogenous colloids.

Until recently most investigators, especially in Europe, have objected to the use of high-protein barley for brewing purposes on the grounds that such barleys give less extract and that this quality is more or less intimately correlated with the flinty character of the endosperm. The latter characteristic is generally held to be an undesirable quality rendering the dissolution of the barley kernels more difficult and resulting in glassy malt. Haase has taken an extreme view of the situation and condemned all barleys containing over 10 per cent of protein. This investigator has, however, gradually receded from his original position, because so many authors have shown that good malts (which produce good beer) could be made from barleys containing much over 10 per cent protein, and furthermore, during 1905, 75 per cent of the Silesian barleys on which he based his argument for low-protein barley contained over 11 per cent of protein.

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[a] Zts. gesam. Brauw., 1904, **27**: 558.
[b] Allgem. Zts. Bierbrau. Malzfabr., 1906, **34**: 513.
[c] Ibid., 1908, **36**: 102.
[d] J. Inst. Brew., 1907, **13**: 328.

Regarding the relation between extract yield and the percentage of nitrogen, Neumann [a] substantiates Haase's law that an increase of protein is regularly followed by a decrease in extract. His conclusions are that a good brewing barley should not only contain a low percentage of protein but should give a high extract yield. Furthermore, in high-protein barleys the carbohydrates are more energetically consumed in respiration. On the other hand, a good, distiller's barley may be high in protein, but its most essential quality is its high diastatic power.

Wahl, in his previous writings, has shown that moderately high-protein barleys, when properly malted and brewed, may give even better results than low-protein barleys, as the former are possessed of high vital energy and develop strong enzymatic power during malting, so that the resulting malts are especially rich in both diastase and peptase. The malts from such barleys are not only able to properly saccharify more starch than they themselves contain, but during malting and mashing a comparatively large quantity of protein is rendered soluble by the peptase, the beers produced from such malts being richer in nitrogenous compounds than beers produced from low-protein barley malts.[b]

In his work on malt and beer, Evans [c] shows that though the nitrogen question is of importance, it is secondary to the study of the starch conversion products produced during malting and mashing. He intimates, however, that much of the color, flavor, and foam of beer is due to the presence of the nitrogenous constituents. Another investigation of importance which should be mentioned is that of Bleisch and Regensburger,[d] which showed that the amount of husks increased with the nitrogen, and the loss during malting also grew larger. They advocate the direct determination of the extract as a factor furnishing more reliable data as to the brewing value of barley and malt than does the determination of nitrogen.

Luff's [e] work, however, showed no relation between the amount of husks and the percentage of protein. He determined the percentage of husk by treating 150 kernels of barley with 10 cc of 5 per cent ammonium hydroxid in a closed flask, heated in a water bath at 80° C. for one hour. On transferring the kernels from the flask, the husks may easily be separated from the grains. Haase and Bauer [f] have shown that a winter barley contains more husks than one with a shorter period of growth and a late ripening variety more than an

[a] Wochenschr. Brau., 1905, **22**: 98.
[b] Wahl, Amer. Brew. Rev., 1904, **18**: 485.
[c] J. Inst. Brew., 1906, **12**: 209.
[d] Zts. gesam. Brauw., 1905, **28**: 628.
[e] Ibid., 1898, **21**: 603.
[f] Wochenschr. Brau., 1907, **24**: 535.

early ripening one. The amount of husks is greater in the starch-poor grains than in full, plump grains, and there is a tendency toward an increase of husks as the weight per 1,000 grains decreases. The husk content does not seem to be influenced by the soil, fertilizers, or width of drills. It is more a varietal characteristic and depends much upon the length of the growing period.

In their paper on conditions affecting the quality of barley Munro and Beaven [a] found that the amount of nitrogen in the grain depends more on the character of the season than upon soil conditions, and that the application of phosphates as a fertilizer improves the quality of barley to a greater extent than does the use of potash, soda, or magnesia, while barnyard manure increases the yield, but lowers the general quality. They also found that the lack of color in a barley, which is often due to bad weather conditions, can be remedied by artificial drying. Schneidewind [b] showed that with the same conditions of manuring, crops which were high in yield were generally low in protein content. Wein's [c] experiments pointed out that nitrogen and phosphates promoted protein formation and that potash influenced the yield and the percentage of starch, thus improving the quality of the crop. He also showed that the barley plant required a large amount of plant food at the early stages of growth.

Voelcher [d] showed that the application of nitrogenous fertilizers alone gives a barley of low weight per bushel and of low valuation for brewing purposes, but of high quality from a distiller's standpoint. He quotes Hall as saying that the variety of the barley, rather than the manure used, exerts the chief influence on the nitrogen content. Manuring exerts no influence on the thickness of husks. In this connection Eckenbrecher [e] has conclusively shown that climatic conditions and soil exert a far greater influence on the amount of nitrogen, the weight per 1,000, and the weight per bushel than does variety or species. This author grew 6 different varieties of barley in 12 different localities and found that every variety grown in any one locality had very nearly the same percentage of nitrogen, weight per 1,000, and weight per bushel, but that any one variety when grown in the 12 localities showed a marked difference in composition, in size, and in weight of berry; in fact, whereas in one locality a certain type of barley contained 9 per cent of protein, in another locality the protein content was over 14 per cent. Tedin [f] also has shown that the protein content is not a race characteristic, and Kiessling [g] has demonstrated that the nitrogen content of barley is more dependent on the weather conditions and

[a] J. Roy. Agr. Soc., 1900, **11**: 185.
[b] Wochenschr. Brau., 1905, **22**: 29.
[c] Zts. gesam. Brauw., 1906, **29**: 141.
[d] J. Inst. Brew., 1906, **12**: 408.
[e] Wochenschr. Brau., 1907, **24**: 491.
[f] Bot. Centrbl., 1907, **104**: 383.
[g] Zts. gesam. Brauw., 1908, **31**: 84.

the nature of the soil than upon variety. The size of grain, however, he considers generally a racial characteristic. In his experiments with barley Reitmair found that phosphorus did not affect the protein content, that there was no relation between the nitrogen of the seed and that of the crop, and that the extract yield and protein content are not transmittable qualities.[a] According to Hubert,[b] the yield and protein content are dependent on the weather conditions between the flowering and ripening periods, and the application of fertilizers can not overcome the climatic conditions. The same author emphasizes the necessity of having pure barley races, which can be obtained only with the assistance of the botanist. He shows further that pure races will grow more evenly and will give more uniform results on the malting floor.

Regarding experiments on the changes in composition which take place during malting, Windisch and Vogelsang[c] showed that in germination and mashing the organic phosphorus of barley and malt is hydrolyzed into the inorganic form. They corroborated the results of Hart and Andrews,[d] who showed that there was practically no inorganic phosphorus in barley. Schulze and Castoro[e] likewise found that in malting part of the organic phosphorus compounds were converted into the inorganic form soluble in water; that in mashing nearly all of the phosphorus compounds were thus transformed, and that the phosphates found in beer wort were inorganic.

In studying the changes which the proteins undergo during malting and mashing, Weis[f] found that the amount of soluble protein increased while the salt-soluble and alcohol-soluble nitrogen compounds, globulin and hordein, respectively, decreased, new compounds with other characteristics being formed in their stead.

Several recent contributions discuss the botanical and physiological characters of the barley plant in more or less detail. Barnstein[g] discusses not only the chemistry of barley, its digestibility and use as a food, but also its anatomical characteristics. He shows that the aleuron layer may be two or four cells in thickness, a fact which may have important bearing when high-protein barley is being considered for brewing purposes, for it has been shown that this layer remains practically unchanged during the processes of malting and mashing. Beaven[h] brings out the morphological differences between the

[a] Vaňha, Kyas, Bukovansky, Chem. Centrbl., 1905, **76**: 695.
[b] Ann. brass. dist., 1907, **10**: 347.
[c] Wochenschr. Brau., 1906, **23**: 556.
[d] New York Agr. Exp. Sta., Bul. 238.
[e] Zts. physiol. Chem., 1904, **41**: 477.
[f] Zts. gesam. Brauw., 1904, **27**: 385, 405, 420, 440.
[g] Landw. Vers.-Stat., 1905, **63**: 275.
[h] Loc. cit.

varieties, giving a classification based on the varying structure. He has shown that the amount of husks or palæ is greater in 6-row barleys and that they act as a protection against mold. Barleys have also been studied from the physical and botanical view points by Lloyd,[a] Broili,[b] Atterberg and Tedin,[c] and in this country by Nilson.[d] The last mentioned has shown that the common Oderbrucker or Manchurian barleys are made up of two distinct types, one with short and the other with long haired basal bristles, the former predominating to the extent of about 80 per cent. Besides this difference, it has been noted that the first pair of veins on the husk on the dorsal side of certain barleys are dentated like a saw, while in other grains the veins are smooth. These and other similar morphological differences are used in distinguishing the varieties of barley, but Broili has shown that there are many other varietal differences, for example, the hairiness of the lodicules, all of which must be considered in determining whether a race is pure.

An important study has been made by Wilfarth, Römer, and Wimmer[e] on the amount of plant food assimilated by barley during the period of its development in the field. These authors analyzed the growing barley at four different stages of growth for the usual plant constituents and found that at the heading period more potash, soda, and nitrogen are present in the plants per acre than at any subsequent period. The explanation given is that the roots of the growing plant excrete these plant-food elements. More recent investigations by Le Clerc and Breazeale[f] showed that the assumption of such an excretion through the roots of growing barley or other plants is erroneous. These authors found that the great loss of plant-food elements noted in barley during the growing period is caused by rain and other atmospheric agencies.

KINDS OF BARLEY.

Barley has been grown for thousands of years. According to Doctor Lauth[g] it was grown in China some two thousand years ago, and in Egypt even as far back as six thousand years, as is shown by the pictures of sheaves and ears of *Hordeum hexastichum* on ancient coins. It thrives in widely different climates, from Algeria to Nor-

[a] Amer. Brew. Rev., 1906, **20**: 79.
[b] Dissert. Jena, 1906; also J. Landw., 1908, **56**: 121.
[c] Wochenschr. Brau., 1907, **24**: 172.
[d] Amer. Brew. Rev., 1904, **18**: 413; 1906, **20**: 475.
[e] Landw. Vers.-Stat., 1905, **63**: 1.
[f] U. S. Dept. Agr., Yearbook, 1908.
[g] Amer. Brew. Rev., 1906, **20**: 258.

way and Iceland, and will even grow at an elevation of over 10,000 feet.

The greater portion of the barley grown in this country is 6-rowed, most of which is of the Manchurian type, commonly called "4-rowed barley." This barley is grown principally in the North Central and Middle Western States and the States of the Great Plains. The original source of this barley was Manchuria. From there it was introduced into Germany about 1859, and in 1861 was introduced into Wisconsin, where, on account of its prolific character, it rapidly spread. The barleys discussed in this bulletin may be classified as follows:

The 6-row barleys of the Manchurian and similar types have a relatively high protein content, generally above 11 per cent, the berries being rather small (from 25 to 32 grams per 1,000), with medium thickness of husks. They germinate on the floor in about five days, the malts having rather high enzymic power. Hayduck[a] established the fact that a high protein malt has a correspondingly high diastatic power. Such barley is, according to Wahl, especially adapted for the preparation of chill-proof beers and for pasteurized bottled beers. The extract from fine grist may be as high as 75 per cent. The Oderbrucker is similar to the Manchurian in all particulars and was introduced into this country about eight years ago by the Wisconsin Agricultural Experiment Station. Although the malt produced from this barley is quite generally used in brewing in this country, it is especially adapted on account of its high enzymic powers for the production of alcohol.

In the Pacific coast States a similar form, known as "Bay Brewing," is being quite extensively grown. In Utah, and a few local points in other States, there is grown a type of barley locally known as "Utah Winter" (sometimes called "White Club"), with 6 symmetrically arranged rows, which is adapted to brewing purposes. Both of these barleys have a rather low protein content, generally below 10.5 per cent, a high weight per 1,000 (30 to 40 grams), require a longer time for germination, and develop less enzymic power. The fine grist yield of extract from Bay Brewing barley malt is about 68 to 70 per cent, and from Utah Winter, 71 to 74 per cent. The Bay Brewing variety has a thick husk, while the Utah Winter has a relatively thin husk. The 2-row barleys are grown in Montana, Idaho, Colorado, and California. They contain less than 11 per cent of protein on an average, weigh about from 35 to 40 grams per 1,000, have thin husks, require a longer time to germinate than does the 6-row variety of the Manchurian type, and develop less enzymic power. The fine grist yield of extract from malts of Hanna or Chevalier type is from 75 to 80 per cent.

[a] Delbrück, J. Inst. Brew., 1906, 12: 643.

Each kind of barley, whether 2-row or 6-row, varies in the number of glassy kernels and in its physical and chemical characteristics according to the conditions under which it grew, the climate playing a prominent part in the production of a low or high protein barley and, in fact, in the production of a first-class barley or one of undesirable quality.

BARLEY VALUATION.

THE BERLIN AND VIENNA SYSTEMS.

To value a barley for malting or brewing is to ascertain the physical, chemical, and physiological properties which it possesses. The maltster, the agricultural distiller, and the brewer are offered all grades of barley. They must know how to judge each, be able to distinguish the favorable or unfavorable factors, and to calculate the value of the product therefrom; and for this purpose various systems of valuation have been evolved. These should not only be exact, but also be simple enough to allow the various factors to be easily and quickly determined. For brewing purposes, malt forms the raw material from which the product is made; from the distiller's view point, malt is but the means to an end. Thus barley is more or less valuable according to the class of malt it will yield and the use to which this malt is put.

The two methods most frequently used for the valuation of brewing barley were the Berlin and the Vienna systems. The former is somewhat older than the latter and depends mainly upon subjective tests—that is, data obtained from outward observation or perception—whereas the Vienna system relies more on objective tests; that is, on data determined in the laboratory by scientific methods. Although these systems are primarily used in valuating barley for brewing purposes, they may be applied to distillers' barley when properly interpreted. Since the systems were first introduced, they have undergone a number of modifications. The Berlin system, as modified in 1908, according to Cluss,[a] involves the following factors: (1) Protein in dry substance, (2) color, (3) uniformity, (4) weight of 1,000 grains, (5) fineness of husks, (6) mealiness, and (7) purity of sample. From the sum of these factors are deducted from 1 to 24 points for injured grains, germinated grains, and bad odor.

Each determination is valued on a basis of 9 points, and, in addition, the most important factors, Nos. 1, 3, 4, and 5, are valued on a double basis (2×1–9 points). Neumann[b] also multiplies the factor "purity" by 2, and Cluss[c] gives a double value to "mealiness." It is thus possible for a perfect barley to be rated at 100 points, in

[a] Monatsh. Landw., 1908, No. 1.
[b] Wochenschr. Brau., 1907, **24**: 421.
[c] Loc. cit.

which case it is designated as "very fine." When a barley has been given less than 18 points, it is considered bad.

Quality of barley as reckoned by points.

18–30	Poor.	67–78	Good to fine.
31–42	Fair.	79–90	Fine.
43–54	Medium.	91–100	Fine to very fine.
55–66	Good.	Over 100	Very fine.

Valuation of barley according to protein content.

(Modified Berlin system.)

Protein content.	Designation.	Valuation by points.
Per cent.		
Over 14	Bad	1 × 2=2
13.1–14	Poor	2 × 2=4
12.1–13	Fair	3 × 2=6
11.6–12	Medium	4 × 2=8
11.1–11.5	Good	5 × 2=10
10.6–11	Good to fine	6 × 2=12
10.1–10.5	Fine	7 × 2=14
9 –10	Fine to very fine	8 × 2=16
Under 9	Very fine	9 × 2=18

The protein content together with the weight per 1,000 grains form the two principal factors, and more than any others indicate the extract yield of the malt. Neumann[a] considers that they are a better guide in this respect than the determination of extract in barley.

Total number of points obtainable for barley rated according to protein content.

Protein content.	Maximum total valuation.	Protein content.	Maximum total valuation.
Points.	*Points.*	*Points.*	*Points.*
2	16	10	59
4	26	12	70
6	37	14	81
8	48	16	92

The value of having uniform grains is that the barley takes up moisture more evenly on steeping and grows at the same rate on the floor, the dissolution of the endosperm being thus more uniformly effected. The purity of the grain is obtained by shaking 100 grams of barley in a set of sieves, graded at 2.2, 2.5, and 2.8 mm, at the rate of from 210 to 220 revolutions per minute for three minutes. In this way the uniformity factor is also obtained. The greater the proportion of the barley found on any two adjacent sieves the higher is the uniformity factor, or inversely; when less than 50 per cent of the barley is found in sieves Nos. I and II, or Nos. II and III, the

[a] Loc. cit.

rating is 1×2, or 2 points. The more evenly the sample is divided among the three sieves the less uniform it is.

Rating of barley by proportion found on adjacent sieves.

[Modified Berlin system.]

Barley found.	Points as rated.	Barley found.	Points as rated.
Per cent.		*Per cent.*	
50–60	2×2 or 4	80–85	6×2 or 12
60–70	3×2 or 6	85–90	7×2 or 14
70–75	4×2 or 8	90–95	8×2 or 16
75–80	5×2 or 10	Over 95	9×2 or 18

The weight per 1,000 grains is also doubly valued. The valuation as based on the dry weight of 1,000 grains is shown in the following table:

Valuation of barley as calculated from weight of a thousand grains.

(Modified Berlin system.)

Weight of 1,000 grains.	Points as rated.	Weight of 1,000 grains.	Points as rated.
Grams.		*Grams.*	
Under 30.	1×2 or 2	43–44.9...	6×2 or 12
30–34.9...	2×2 or 4	45–46.9...	7×2 or 14
35–37.9...	3×2 or 6	47–48.9...	8×2 or 16
38–40.9...	4×2 or 8	Over 49..	9×2 or 18
41–42.9...	5×2 or 10		

The principal change as compared with the former Berlin system is that of giving double value to the protein, uniformity, weight of grain, fineness of husks, and sometimes to purity and mealiness, and making the whole number of points obtainable depend on the protein content. The first Berlin system was restricted to the following tests: Color, weight, uniformity, fineness of husks, mealiness, and purity of samples, together with the negative points, namely, odor, damaged grains, and started grains. In 1897 the protein and weight per hectoliter were added to these subjective tests. Since 1903, under the influence of Haase, the nitrogen factor has become predominant in the Berlin system, this and the size of the grain, or weight per 1,000, constituting the two chief factors of this system.

The present modified and improved Vienna system is based on the following objective factors:[a] (1) Weight per hectoliter; (2) weight per 1,000; (3) screenings (assortment); (4) impurity; (5) real steeliness; (6) protein; and on the following subjective factors: (1) Color; (2) uniformity; (3) shape of grain; (4) fineness of husks; (5) general impression, deducting for odor and injured grains.

[a] Vorschrift für die Vorbereitung u. Durchführung der Bonitierung der Gerstenprobe, Wien, 1907.

OBJECTIVE FACTORS.

The weight per hectoliter is obtained by actual weighing of the sample. The points given for this factor are as follows:

Valuation of barley according to weight.

Weight of barley.			Rating.
Per hectoliter.	Per bushel.	Per thousand.	
Kilograms.	*Pounds.*	*Grams.*	*Points.*
Over 70	54	Over 38.5	3
67–70	52–54	36.5–38.4	2
66–67	51.3–52	35–36.4	1
Under 66	51.3	Under 35	0

The assortment factor is obtained from the percentage of the sample which passes through a 2.2 mm sieve, and the sample is rated on this point as follows:

Per cent.	Points.	Per cent.	Points.
0–1	4	3.1–4	1
1.1–2	3	4.1–5	0
2.1–3	2		

Impurity means the amount of weeds, chaff, dirt, etc., which a sample may contain, and is rated as follows:

Per cent.	Points.	Per cent.	Points.
0–0.2	4	1.1–1.5	1
0.3–0.5	3	Over 1.5	0
0.6–1	2		

Real steeliness or permanent steely grains are given the following points:

Per cent.	Points.	Per cent.	Points.
0–10	6	40–50	2
10–20	5	50–60	1
20–30	4	Over 60	0
30–40	3		

Protein (on dry basis) is rated as follows, all barleys containing more than 14 per cent being rejected:

Per cent.	Points.	Per cent.	Points.
Under 10	6	11.5–11.9	2
10–10.4	5	12–12.9	1
10.5–10.9	4	13 and over deduct	2
11–11.4	3		

SUBJECTIVE FACTORS.

Color is graded as follows: Very good, 3; good, 2; medium, 1; bad, 0.

The uniformity and shape of the kernels is graded: Excellent, 4; very good, 3; good, 2; medium, 1; bad, 0.

The shape for brewing purposes is preferably plump and well closed. Too thin kernels, or even too plump kernels, are of less value.

The fineness of the husks indicated by the wrinkles and folds is given the following values: Especially fine, 6; very fine, 5; fine, 4; less fine, 3; rather coarse, 2; coarse, 1; thick skin, 0.

The factors odor and injured grains are negative; that is, 1 point is deducted for bad odor and 2 points for injured grains. General impression is graded as follows: Excellent, 3; very good, 2; good, 1; bad, 0.

It is seen that the Vienna system relies more on the laboratory and scientific method than does the Berlin system, and is an improvement not only in this respect, but also in that it values the different factors according to their importance and attaches less weight to the protein content of the barley.

According to the Berlin system the principal factors[a] in barley valuation are protein content, mealiness, the percentage of husks, and the fineness of husks. Next in importance come the siftings and uniformity of grain, and of least importance are weight per bushel, weight per 1,000, and color. Cluss considers the protein content as the most significant factor, and that the weight per bushel, weight per 1,000 grains, and amount of husks indicate the amount of valuable constituents in barley. He also finds objections to taking the percentage of husks into consideration on the grounds that a properly thrashed barley would contain more husks, and therefore be prejudiced in comparison to short and possibly injured grains.

Haase[b] claims that the husks and the shape of the grain afford a certain indication as to quality, but are of secondary importance, stating that, as a rule, the finer the husks the greater the number of damaged kernels.

According to Prior,[c] the subjective tests should be considered only in connection with the chemical and physical tests. He believes that the color may indicate the presence of unripe grains or those slightly damaged and browned by bad weather conditions, and the shape may give indication as to variety and fitness for brewing, the plump grains being ordinarily better than the long, thin grains because they contain more starch as well as more nitrogen. The weight per bushel, in connection with the weight per 1,000 grains, is important in showing whether or not a sample consists of light barley and therefore contains less starch and produces less extract. Very heavy grains, however, malt rather stubbornly, and on that account medium-size barley is preferred. Prior would not consider the protein content as of much importance except when above 13 per cent. When below 13

[a] Cluss, Allgem. Zts. Bierbr. Malzfabr., 1906, vol. 34, No. 8.
[b] Wochenschr. Brau., 1906, **23**: 35.
[c] Allgem. Zts. Bierbr. Malzfabr., 1907, vol. 35, January.

per cent the nature of the protein constituents should be considered. Both Regensburger [a] and Kukla [b] agree with Prior that the quality of the nitrogenous constituents rather than the total nitrogen must be considered in valuing the barley.

Prinz [c] suggests that the points in the valuation of barley should be, first, maturity of the grain, which he considers of greatest importance; second, the protein content; then the uniformity, odor, husks, shape, and damaged grain, in the order named. Uniformity, mellowness, and soundness are more important than color. Furthermore, in all commercial transactions both barley and malt should be bought and sold on the basis of hundredweight rather than per bushel. Hoffmann [d] advocates buying barley and malt on the dry basis, as only dry grain is stable, it being less liable to damage and to attack by mold, besides costing less for transportation. This is certainly a most reasonable proposition, just equally to buyer and seller. It is no unusual occurrence for a grain to lose several per cent of moisture in being transported from one locality to another as, for example, from a humid to a dry climate.

Regarding other criticisms of these European systems, Eckhardt [e] considers the assortment factor obtained by means of the 2.2, 2.5, and 2.8 mm sieves as of the greatest importance, after the degree of mealiness and the amount of protein, as it shows how uniform the grain is. Bleisch [f] suggests that the only criterion in the valuation of barley is a malting experiment on a small scale. Biffen [g] regards a barley of good quality if it is mature, mealy, free from broken and discolored grains, germinates freely and uniformly, and has a good color and a finely wrinkled surface. Heron [h] and Salamon [i] consider the diastatic power of malt as an exceedingly useful determination. Besides this, Heron generally estimates the percentage of extract, the specific rotatory power, tintometer value, and moisture, all of which give valuable information concerning malt. Hunicke [j] looks on the physical character of the endosperm as the most important factor, giving greatest weight to the extract content, while Wallerstein considers the loss during malting as the most important determination. As regards the proteins, Wallerstein considers those formed in malting and found in mashing as of greater significance than the total protein. Kreichgauer [k] suggests that the weight per bushel in connection with the biting test will give a good starting point con-

[a] Zts. gesam. Brauw., 1905, vol. 28, Nos. 35 and 36.
[b] Ibid., 1900, **23**: 418.
[c] Amer. Brew. Rev., 1907, **21**: 589.
[d] Wochenschr. Brau., 1906, **23**: 534.
[e] Zts. gesam. Brauw., 1906, **29**; 523.
[f] Zts. gesam. Brauw., 1899, **22**: 327.
[g] J. Inst. Brew., 1906, **12**: 345.
[h] J. Fred Inst. Brew., 1902, **8**: 666.
[i] Ibid., p. 2.
[j] J. Amer. Chem. Soc., 1904, **26**: 1211.
[k] Wochenschr. Brau., 1905, **24**: 171.

cerning the value of the barley. In a later communication Jalowetz[a] recommends that the protein content of the individual grains be taken into consideration instead of the percentage of protein.

A good barley should be sound, have a high germinating power, be rich in starch, and, according to the European system of valuation, low in protein. That the first requisite for good barley is life, high germinating power, and uniform germination needs no discussion, and these may best be obtained by the production of pure races. To both systems there are more or less valid objections made, even by European investigators; though, on the whole, they apply very well to European barleys and conditions. Neither system could, however, be applied in valuing American 6-row barleys, since the conditions both in respect to the type of barley and to the requirements of the brewers are so different in the United States from those prevailing in Europe that the valuation must be made on another basis.

Besides all these factors, a knowledge of the locality of production, the weather conditions prevailing during the growing period and at harvest, the fertilizers used, and the rotation of crops practiced, etc., may aid in estimating the value of barley. For example, it is well known that a late rain discolors the grain and makes it less valuable, and a heavy application of nitrogenous fertilizers tends to increase the protein content, while, on the other hand, much sunshine prevailing during the growing season tends to assure a better grade of barley.

Although all the factors enumerated in both systems are important to a greater or less extent, from a brewer's view point, yet, for the production of alcohol in the agricultural and industrial distillery, some of them may well be given a secondary position. Such factors as fineness of husks, mealiness of endosperm, shape of grain, impurity, and color are of less importance in alcohol production than in the brewing industry, though even these factors are of help in valuing a distiller's barley. Recently harvested barleys have a low germinating power, therefore they should not be malted until at least three months old. The diastatic power of malt is the chief factor when used for alcohol production. This factor is more or less influenced by the characteristics of the grain; namely, uniformity as regards race and age of barley, weight per 1,000 grains, and protein content. A good distiller's barley should have the following characteristics: High germinating power, high protein, uniformity, good color and odor, and cleanness. The malt produced therefrom should possess a high diastatic power, have a pleasant odor, a sweet and agreeable taste, and be free from dirt. As a barley rich in nitrogen is generally one which will yield a malt of high enzymic power—

[a] Amer. Brew. Rev., 1907, 21: 590.

in other words, be rich in diastase and peptase—a high nitrogen content of barley is more essential for distillery purposes than for brewing.

ACTION OF THE BERLIN CONGRESS, 1908.

In 1907 the question of barley valuation was considered by the International Agricultural Congress at Vienna, and it was determined to submit it to a special international commission to meet in Berlin in October, 1908. This commission agreed on a general system of barley valuation which, however, was not to be applied to 4 or 6 row barleys. The principles underlying the new international valuation system are:

1. To establish a general system of valuation not considering varieties.
2. To create three grades of value—a highest, a medium, and a lowest.
3. To adopt eleven points for valuation, classified as follows:

Highest class:

1. Protein content (penalties for excessive protein being omitted).
2. Bad odor.

Second class:

3. Uniformity (as to size).
4. Weight (1,000 kernels).
5. Fineness of husk.
6. Damaged grains.

Lowest class:

7. Color.
8. Purity of sample (foreign seed).
9. Sprouters.
10. Purity as to variety.
11. Shape of berry.

The following points were omitted from the systems previously described herein:

1. The mellowness of corn, either of the original barley or after steeping.
2. Hectoliter weight.
3. Impression as a whole.
4. Water content of the barley.

The germinating energy was recognized as a valuable point for judging barley, and it was recommended for use at competitive exhibits, but it was considered impracticable for ordinary expositions. This system of barley valuation, as well as the Berlin and Vienna systems which are modified by it, were established for the purpose of serving as guides to jurors of award in judging exhibit barleys, and consequently under circumstances necessitating the judging of large numbers of specimens or samples with dispatch. While in the main the same test points should naturally form the basic features for valuing barley for commercial purposes also, such important points as germinating capacity, the examination for which requires much time, can not well be undertaken for exhibit barleys; besides, exhibits have

usually taken place soon after harvesting, when germinating capacity does not compare favorably with results after proper storage of barley, the higher moisture content alone detrimentally influencing the property of germinating capacity to a decided degree. For this reason and because at the usual exhibit periods moisture content is considerably higher than after storage, it was not included in these systems of valuation. In a commercial system of valuation, however, germinating capacity and moisture content become the main points in the consideration of value, and in the tentative system for American barleys which follows germination capacity forms the basic factor of valuation, to which the importance of all other points or properties is made relative.

TENTATIVE SYSTEM FOR VALUING AMERICAN BARLEY.

The American barleys are to be classified in at least four groups—one comprising the eastern 6-rowed Manchuria barley, cultivated particularly east of the Rocky Mountains; a second, the western 6-rowed barley, the Bay Brewing and Blue barley; a third, the 6-rowed Utah Winter barley; and a fourth, the 2-rowed barleys, the Chevalier, Hanna, Goldthorpe, etc. The western barleys, 2 and 6-rowed, from west of the Rocky Mountains or from the Rocky Mountain territory conform more nearly to the European standard than do the eastern.

For each of these four groups of American barleys a model barley valued at 100 points is used for comparison and more or less points deducted according to the results of each test. A deduction of more than 6 points in any test or division would place a barley below standard.

STANDARD BARLEY.

Standard barley ranges from 94 to 100 points. A barley is below standard when it receives less than 94 points in any one of the examinations of properties described later. For commercial valuation divisions 1 to 8 should be included. For exhibit purposes all tests should be included that are feasible, omitting moisture and germinating capacity for the reasons already given.

The total average of points is found by dividing the sum of the points of each test or division by the number of divisions determined. In this way all divisions need not be included in the test; for instance, moisture, protein, and husk may be omitted by those not having the facilities for making these examinations, and the relative value of the barley nevertheless stands for the remainder of the tests.

CALCULATING THE PERCENTAGES.

The value for each division as stated in points is established by the relative importance of a defection from 100 points, indicating thereby the percentage of inferiority to the assumed model

barley. A barley, for instance, of which 3 per cent do not grow, is rated as 97 for that test or division, a deduction of 1 point being made for each dead berry or germ. The ungerminated barley berries are, however, of greater value than an equal number of grains of wheat or oats, these being too large and heavy to be removed by screening, blowing, or steeping. As wheat or oats may cause protein turbidity in the product, not more than 2 per cent of such grains should be permissible in a standard barley and 3 points should be deducted for every per cent of unremovable foreign matter. For all offal that is removed by screening, blowing, and steeping, only 1 point is deducted for every per cent, because it is not directly harmful. This offal, together with the unremovable foreign matter and the sprouters, should not exceed 6 per cent in a standard barley. This means that a standard barley, after cleaning and skimming, and after deduction has been made for unremovable foreign matter, should yield at least 94 per cent of malting barley.

When valuing barleys from the point of view of the maltster or brewer the deductions for offal should not be included in the final average, which should refer to the cleaned barley. Only for exhibition purposes should the deductions for offal be included in the final average. A barley containing as much as 15 per cent of screenings and skimmings, etc., would only yield 85 per cent of malting barley and could not be considered a standard barley. The 85 per cent of malting barley may, however, be of good or even excellent quality, although probably of low 1,000-berry weight. Its quality is to be determined by the maltster's test (divisions 1 to 12) or the brewer's test (divisions 2 to 14), division 6, offal, being in both cases omitted from the final average. The number of points deducted in one division should be of equal value or importance as indicating inferiority of quality as those in another division. Thus a Manchuria barley with 9 per cent of protein would lose, on account of having 2 per cent less protein than normal, 6 points, and its rate of inferiority would be considered equivalent to that of a barley with 6 per cent of berries not germinated, or with 3 per cent of moisture above normal, or 6 per cent of offal, or 2 per cent of unremovable foreign seeds, or a 1,000-kernel weight of 3 grams below or above the normal. Likewise a barley with 14 per cent of protein, or 2 per cent above normal, would be rated as to inferiority 2×3 points.

This system is equally applicable to all four groups of American barley, but the normal conditions and the requirements to be met by the model barley are somewhat different for each group.

TESTS OR EXAMINATIONS REQUIRED.

For commercial valuation: (a) Merchants' or graders' tests, 1 to 8; (b) maltsters' tests, 1 to 12; brewers' and seed barley tests, 2 to 4.

For exhibit valuation: Tests 2 to 14, excepting 11 and 12.

By subjective examination.

1. Variety and admixtures (Manchuria, Bay Brewing, Utah Winter, Chevalier, etc.): Deduct 1 to 6 points.
2. Color and brightness: Deduct 1 to 6 points.
3. Odor: Deduct 1 to 6 points.
4. Thickness of husk: Deduct 1 to 6 points.
5. General impression; uniformity of form and size of berries (plump or elongated); thrashing (too close or insufficient); maturity: Deduct 1 to 6 points.

By objective examination.

6. Offal:
   By screen: Upper screen: gravel, peas, corn, etc. Lower screen: barley, oats, rye, rape, mustard, etc.
   By water: Skimmings, excluding sprouters.
   By blowers: Straw, barley, oats, etc.
   By cockle machine: Broken kernels, cockle, etc.
   (In each case deduct 1 point for every per cent.)
7. Sprouters: Deduct 6 points for every per cent.
8. Remaining foreign matter (wheat, oats, etc.): Deduct 3 points for every per cent.
9. 1,000-berry weight: Deduct 2 points for every gram above or below optimum.
10. Uniformity as to size (the sum of adjacent screens 2.8 mm+2.5 mm, or 2.5 mm+2.2 mm, or 2.2 mm+2.0 mm, giving the highest figure):
    100 to 80 per cent deduct 0 point.
    80 to 74 per cent deduct 1 point.
    74 to 69 per cent deduct 2 points.
    69 to 65 per cent deduct 3 points.
    65 to 62 per cent deduct 4 points.
    62 to 60 per cent deduct 5 points.
    60 to 58 per cent deduct 6 points.
11. Germinating capacity: Deduct 1 point for every per cent below 100.
12. Moisture: Deduct 2 points for every per cent above 11 per cent.
13. Protein ($N \times 6.25$): Deduct 2 points for every per cent above or below optimum.
14. Uniformity as to variety (by botanical examination): Deduct 2 points for every per cent of foreign barley or different groups (mixtures of 2, 4, or 6 rowed barleys).
15. Husk (not determined unless considered below standard in subjective examination: Deduct 3 points for every per cent above optimum.

Bushel weight and mealiness are not considered. If barley is infested by weevils or other insects or stained or discolored by fungous growths, such as smut, mold, etc., it is absolutely condemned.

PLAN OF THE INVESTIGATION.

SAMPLES AND DETERMINATIONS MADE THEREON.

The investigation undertaken by this Bureau, of which this is the first report, was authorized by act of Congress, the object being to study barleys grown in different parts of the United States in regard to their use for brewing purposes.

The barleys analyzed comprise 84 samples of the 6-row varieties of Oderbrucker and Manchuria, 18 samples of 2-row varieties, 18 samples of thick-skin, so-called "Bay Brewing" barleys, and 9 samples of the thin-skin Utah Winter. From many of these samples malts, which were likewise subjected to critical analyses, were prepared in malting plants on a commercial scale. Realizing that chemical and physical methods must both be used in the attempt to solve such questions as are involved in the improvement of American barleys, it has been found advisable to make the following determinations on all the barley samples: Water, total nitrogen, soluble nitrogen, coagulable nitrogen, extract, fat, fiber, pentosans, starch, sugars, ash, phosphoric acid, sulphur, lecithins, weight per 1,000 grains, weight per bushel, character of the endosperm before and after steeping, degree of solubility, germinating energy and capacity, amount of husks, bran, endosperm, and embryo. The chemical work, however, is given special prominence in this study, for purely physical analyses alone are not enough to determine the value of barley.

The malt samples were subjected to the following analyses: Water, total nitrogen, soluble nitrogen, coagulable nitrogen, extract (fine and coarse grist), fat, fiber, pentosans, starch, sugars, ash, phosphoric acid, sulphur, lecithins, weight per 1,000 grains, weight per bushel, character of the endosperm, the growth and overgrowth of acrospire, the amount of husk, bran, embryo, and endosperm. It was hoped, from all these determinations, that a better insight as to the changes going on during the process of malting would be gained, and that a guide for future work might be obtained.

CHEMICAL METHODS OF ANALYSIS.

The chemical methods of analysis employed in the Bureau of Chemistry were, unless otherwise described, the official methods adopted by the Association of Official Agricultural Chemists. The exceptions were as follows:

Total sulphur was determined according to the sodium peroxid method.[a]

The lecithin determination was made by extracting 10 grams of ground barley or malt with ether, and then extracting the residue repeatedly with absolute alcohol. The ether and alcohol extracts were united, all volatile substances evaporated, and the residue burned with caustic soda to an ash. The ash was then treated in the usual way for phosphoric acid. The amount of phosphoric acid multiplied by 11.37 gives the lecithin content. It is well known that alcohol will extract other phosphorous bodies besides lecithin proper—for example, kephalin; these figures, therefore, include all the lecithin-like bodies soluble in alcohol and ether.

[a] Le Clerc and Dubois, J. Amer. Chem. Soc., 1906, 28: 1108.

The soluble proteins were determined by the following method, described by J. S. Chamberlain:

An amount of air-dried barley or malt equivalent to 20 grams of dry material was extracted with water of such a volume that the total resulting mixture amounted to exactly 100 cc. In order to know the volume of liquid in such an extraction it was necessary to determine the volume occupied by the residue from 20 grams of the dry barley after extraction, which was found to be 10.77 cc. In calculating this volume, the figure obtained by H. T. Brown [a] for the specific gravity of the dry residue of extracted barley was used, namely, 1.57. Subtracting the volume occupied by the dry residue of extracted barley from the 100 cc gives the volume of liquid actually present. An aliquot of this volume was taken after filtration and the nitrogen determined therein. In practice, however, an amount of barley was taken such that in the proportion of 20 grams of dry substance to 100 cc of the resulting extraction mixture there will be present, after allowing for the volume occupied by the extracted barley, exactly 100 cc of liquid. In this way aliquots of 10 cc, 25 cc, or 50 cc could be easily obtained; that is, 22.41 grams of dry barley in the proportion of 20:100 will require a volume of extraction liquid equaling 112.05 cc, and 22.41 grams of dry barley will leave after extraction a dry residue equaling 12.06 cc. Therefore the volume of liquid present equals 112.05—12.06=99.99 cc.

The amount of air-dry barley to be used was then easily calculated in each case from the percentage of moisture in the sample, and this weight of air-dry material was added and extracted under the conditions just described. For the extraction, distilled water at room temperature was used, and the bottles in which the extraction took place were shaken in a revolving shaker for six hours. The mixture was then filtered as rapidly as possible through folded filter papers, the first portion of filtrate, when cloudy, being poured back upon the filter paper until a clear filtrate was obtained. In an aliquot of this clear filtrate the amount of nitrogen was determined, which, multiplied by 6.25, gave the protein, representing the soluble protein.

The soluble noncoagulable protein was determined by boiling 20 cc of the above filtrate over a small flame until the volume was reduced to about 10 cc. After diluting to the original volume, the liquid was filtered, washed, and the noncoagulable nitrogen determined by using the whole of the filtrate.

The soluble coagulable proteins were determined by subtracting the soluble noncoagulable protein from the total protein.

The determinations made by Wahl, which require special mention, were as follows:

For the soluble protein determination 50 grams of finely ground barley were extracted with 250 grams of water for six hours at 18° C. ±1°, stirring well every fifteen minutes. The loss on evaporation (approximately 0.1 gram) was made up by adding water until the total weight equaled 300 grams. The extract was filtered clear, maintaining approximately the same temperature. The total soluble nitrogen was determined in an aliquot of the filtrate according to Kjeldahl's method.

The coagulable nitrogen was determined by boiling 100 cc of the above filtrate for thirty minutes, keeping the volume constant, filtering, and estimating the nitrogen in the precipitate. The factor 6.25 was used in all determinations in changing the percentage of nitrogen into protein.

[a] Loc. cit.

For the determination of the extract in barley the following method was used by Wahl:

Twenty-five grams of finely ground barley were macerated with 200 cc of distilled water at 65° C. and 25 cc of diastase solution added. The whole was immediately placed in a boiling water bath and kept at that temperature for one hour. The mash was then removed from the bath, boiled briskly for five minutes over a direct flame, stirring continuously, cooled to 60° C., and 75 cc of the diastase solution added, the temperature being kept at 60° to 75° C. for thirty minutes, then raised to 70° C., and held there for another thirty minutes. After inversion, the mash was cooled to from 10° to 15° C., the weight made up to 350 grams with water, and then filtered. The specific gravity of the filtrate was determined by means of the pycnometer. One hundred cubic centimeters of diastase solution were then treated in the same way as was the barley mash, and after cooling were made up to 100 cc, and the specific gravity determined as before. The percentage of extract is calculated as follows:

$$\frac{\left(W+\frac{MN}{100}+wd\right)}{100-B}=e,\ \frac{(e-ed)\ 100}{N}=E,$$

in which—

W=weight of water used in the mash.
M=percentage of water in the barley.
N=weight of barley used.
wd=weight of water in the diastase solution used.
B=percentage of extract in mash filtrate according to Balling.
e = extract in 25 grams of barley and 100 cc of diastase solution.
E=percentage of extract in barley.
ed=extract in diastase solution used.

The diastase solution was made by digesting 500 grams of finely ground malt with 2 liters of water for one hour at 15° C.

Wahl's method for the determination of the extract yield[a] of the malt was as follows:

Fifty grams of the malt plus 3 kernels are finely ground into the mashing beaker and are macerated with 250 cc of water at 45° C., immediately raised to 45° C., and kept at this temperature for thirty minutes. The temperature is then raised 5° each five minutes until the thermometer shows 70° C. The mash is held at this temperature for thirty minutes. The iodin test is made when the mash reaches 70° C., and is repeated every five minutes until inversion has taken place. The mash is then cooled to about 15° C., and its net weight is made up to 450 grams by the addition of water. The mash is thoroughly mixed, and a quantity of clear wort, sufficient for the saccharometer determination, is filtered through a coarse filter. The liquid is brought to a temperature of 15° C. Its saccharometrical indication is determined by a special Balling instrument standardized at 15° C. and divided into 0.05 per cent. The yield is calculated by the following formula, in which "S" is the saccharometer indication, "H" the percentage of water in the malt (both expressed in percentage of the malt), and "E" the yield of extract:

$$E=\frac{S\times(800+H)}{100-S}$$

[a] Report of the Analysis Committee, U. S. Brewers' Association, 1902.

The yield of extract on the dry basis E′ is computed from "E" by the following formula:

$$E' = \frac{E \times 100}{100 - H}$$

Windisch's extract tables should be employed. The saccharifying or diastatic power of the malt is regarded as very good, if the iodin test shows the absence of starch in the mash, when the temperature has reached 70° C.; as good, if inversion takes place within five minutes, and as fair, if inversion takes place after ten minutes.

To determine the protein dissolved by mashing, 25 cc of mash filtrate were evaporated almost to dryness and nitrogen determined according to Kjeldahl's method, the coagulable protein being determined in the same manner as in barley.

The growth is the ratio of the length of the acrospire to that of the kernel. The determination was made in duplicate by sorting 50 kernels.

The color of the wort was tested by Lovibond's tintometer and the run of the wort by personal judgment. The other determinations were conducted in the same manner as for barley.

MECHANICAL AND BIOLOGICAL METHODS OF ANALYSIS.

The weight per 1,000 grains was determined in the Bureau of Chemistry by means of Kickelhayn's apparatus.

The hulls, bran, embryo, and endosperm were all determined in the Microchemical Laboratory by mechanical dissection of the grain. The method of procedure is described by W. J. Young as follows:

From 6 to 8 good, average grains were selected, and after weighing they were soaked until the hulls could be removed readily, being then subjected to further soaking until the endosperm was completely softened. The grains were finally split lengthwise, and the endosperm removed under water. The hulls, bran, and embryos were placed by themselves in watch glasses, and dried at 100° C. until loss of weight ceased. The water containing the endosperm was allowed to stand in a beaker until the starch settled, when the water was decanted and the sediment dried with gentle heat until moisture was no longer apparent, when the drying was completed at 100° C. More or less loss was observed as a result of this method of drying the endosperm, and this loss was so great in the case of the malts that in these the endosperm was determined by difference.

In the later work on barleys the endosperm was determined by difference in order to obtain results comparable with those obtained from the analysis of the malts.

The physical tests as made by Wahl are as follows: The character of the endosperm was determined by using the Kickelhayn grain cutter. This apparatus cuts 50 berries in two lengthwise at one time. The halves are then easily divided into three groups, namely, those

with a steely endosperm, those that are mealy, and those that are partly steely and partly mealy, or intermediate.

The character of the endosperm after steeping was determined as follows:

Fifty grams of barley were steeped in water at from 15° to 20° C. for twenty-four hours. The water was then poured off and the excess removed from the grains by means of blotting paper. The barley was dried in a drying oven at 30° C. with low draft until the weight approximated slightly less than the original amount taken, about 49 grams. The cutting was done in the same manner as described above.

The germinating energy is represented by the percentage of grains germinated within three days at ordinary temperatures. The germinating capacity is expressed as the percentage of grains which germinated in five days. These tests were made by the ordinary methods for testing germination. The weight per bushel was found by weighing a miniature bushel.

The degree of dissolution was determined by Prior's method:

Steep the barley in distilled water for twenty-four hours at 15° C., drain off the water, removing the excess of moisture by means of filter paper, and dry at 40° C. in an air bath for about two days; then determine the mellowness by means of Kickelhayn's apparatus. Prior considers the mealy grains which are originally present better than the modified steely grains, and therefore he adds them to the percentage of steely grains modified.

$$A = \frac{(M_1 - M)\ 100}{100 - M} = M,$$

in which

A = degree of dissolution.
M = per cent of mealy kernels in original barley.
M_1 = per cent of mealy kernels in barley after steeping and drying.

The coefficient of mealiness in steeped and unsteeped barley was calculated according to H. T. Brown's[a] formula: Mealy grains are given a value of 100, half mealy 50, and steely 1. The number of grains of each type multiplied by its special value and the sum divided by 100 will give the coefficient of mealiness.

The 1,000 kernel weight is found by counting 500 kernels at random and weighing them on a technical balance. The average of four weighings was taken, unless the difference between the highest and lowest weight of 500 kernels exceeded 0.5 gram, when five or six weighings were taken.

DISCUSSION OF RESULTS.

In discussing the results obtained attention will first be called to the composition of the ordinary 6-row barleys (Table I), the Manchurian and Oderbrucker, calculated to a water-free basis, and then to the change in composition which barleys undergo on being converted into malts. Of the 84 samples of 6-row barleys, the average

[a] Loc. cit.

percentage of protein was 11.86, with a variation of from 10.13 to 14.94 per cent; 52 of these samples contained over 11.5 per cent, while only 12 had less than 11 per cent of protein. The sample containing the lowest percentage (10.13) was from Wisconsin, whereas the sample with the highest percentage (14.94) was grown in Montana. The following is a comparative average of the nitrogen results obtained by the Bureau of Chemistry and by Wahl:

Average percentage results on the nitrogen content of three kinds of barley and malt.

Analyst.	Ordinary 6-row.	Western 6-row.	Two-row.
BARLEY.			
Bureau of Chemistry	1.91	1.69	1.70
R. Wahl	1.93	1.69	1.80
MALTS.			
Bureau of Chemistry	1.84	1.58	1.62
R. Wahl	1.90	1.59	1.65

PROTEIN CONTENT OF BARLEY.

The following table shows the average amount of protein found in the barleys from several States, beginning with the lowest percentage of protein:

Percentage protein content of barleys arranged by States.

State.	Protein content.	State.	Protein content.	State.	Protein content.
Illinois	11.44	Canada	11.83	Montana	12.63
Michigan	11.51	Minnesota	11.90	South Dakota	12.80
Iowa	11.59	Indiana	11.94	Kansas	13.44
Wisconsin	11.64	Colorado	12.50	New York	14.19
Ohio	11.69				

It is thus seen that the North Central States or States of the upper Mississippi Valley produce barleys whose protein content is on an average less than 12 per cent. If it be assumed, as is done in Europe, that a low-nitrogen barley is best for brewing, then these States produce a better quality of barley for this purpose than those grown in Kansas, New York, or South Dakota. On the other hand, the latter States should produce a more nutritious and therefore a better feeding barley and one better suited for the production of denatured alcohol. Clifford Richardson,[a] in 1886, found that the Dakota barley was the richest in protein. The average of his results on 60 samples of this cereal is 12.1 per cent, very little higher than the average of 11.86 per cent here reported.

[a] U. S. Dept. Agr., Division of Chemistry, Bul. 9.

RELATION OF PROTEIN TO STARCH AND EXTRACT.

It is generally assumed that a high protein grain means a low starch grain, and vice versa. This is true, as a rule, and especially so in the case of wheat. When barleys are considered, however, there are many exceptions, notably the barleys from Ohio, Minnesota, Iowa, and Illinois, which have a comparatively low protein content, and also a rather low starch figure, while those few samples from Kansas and Montana, which contain more than the average amount of protein, likewise show more than the average content of starch. The samples of Indiana, Canada, Michigan, and Wisconsin barleys have a somewhat low protein content, while those from New York, Colorado, and South Dakota have a high protein content. Both of these two groups follow the general expectation, for while the former is high in starch, the latter is low. Thus 33 out of 84 samples of barleys are exceptions to the rule that high protein means low starch, and vice versa. As has been noted, in the case of wheat, protein and starch are generally complementary. With barleys, however, the presence of hulls, varying in amount from 10.2 to 15.4 per cent, makes this point less decisive, though an average of barleys grown under similar conditions shows with a high protein content a lower starch figure. The results indicate that on the whole low-protein 6-row barleys do contain more starch. Fifty-three samples, with an average of 12.2 per cent protein, contained on an average 70.6 per cent of extract, while 31 samples, with 11.1 per cent protein, contained 71.8 per cent of extract. The averages from each individual State do not always show this fact, namely, that there is more extract in low-protein barleys, but if instead of averaging all the samples they be separated into high-protein and low-protein barleys, not taking into account those samples whose protein content is close to the average, then the figures will show that high-protein barleys are low in extract, and vice versa. Twenty-four barleys, with an average protein content of 13 per cent (that is, all barleys over 12.25 per cent), compared with 23 barleys whose average protein content is 10.8 (all samples under 11.25), show 69.94 per cent extract in the former and 72 per cent in the latter. In order, therefore, to bring out the different relations it is often best to take the extreme cases and not regard those which are so near the average that they might be included in one class or the other, according to variations within the limits of error. If, however, only the samples from Michigan, Minnesota, Wisconsin, Iowa, and South Dakota (the States where this type of barley has been found especially well suited to the conditions and where it is therefore extensively grown) be arranged in groups ac-

cording to their protein content,[a] a very pronounced tendency in the direction of the theoretical reaction between protein and extract is seen.

Barleys from States of the northern Mississippi Valley showing the relation between protein, extract content, and weight per 1,000 grains.

Number of samples.	Protein.	Extract.	Weight per 1,000 grains.
	Per cent.	*Per cent.*	*Grams.*
2	10.0–10.5	72.68	28.01
9	10.5–11.0	72.12	27.29
19	11.0–11.5	71.63	26.97
13	11.5–12.0	71.15	26.39
9	12.0–12.5	70.70	26.07
9	12.5–13.0	70.19	25.66
4	13.0–13.5	70.16	26.14
4	13.5–14.0	70.71	26.14

Only the last group, containing from 13.5 to 14 per cent of protein, forms an exception to the general rule that the percentage of extract decreases with an increasing protein content. The table further indicates that there is a greater decrease in extract for barley containing from 10 to 12 per cent of protein than in that containing from 12 to 14 per cent.

From these results it is very evident that high-protein barleys of the 6-row type give low extract yields, a fact which has been observed by many others, especially in regard to 2-row barleys.

RELATION OF PROTEIN CONTENT TO WEIGHT PER 1,000 GRAINS.

Neumann[b] showed that low-protein 2-row barleys were generally of higher weight and that they produced more extract. The results here shown indicate also that low-protein barleys of the 6-row type weigh somewhat, though very little, more per 1,000 grains, thus again corroborating Neumann's work. This is shown by the last column of the preceding table, which gives the average weight of 1,000 grains within the different groups. While it would appear from the table as if the weight of 1,000 grains varies more or less irregularly, especially for barleys containing from 12 to 14 per cent of protein, there is an obvious tendency for the weight of 1,000 grains to decrease as the protein content of the barley increases from 10 to 12 per cent, though there are many individual exceptions.

If one considers those samples of approximately the same percentage of protein, it will be found that invariably the heavier contain the

[a] Three samples have been left out which either contained more than 14 per cent of protein or had abnormally large berries, together with much protein, owing to special cultivation and breeding.

[b] Wochenschr. Brau., 1905, **22**: 98.

most extract, a fact already established by Neumann [a] and Kunz.[b] This is well illustrated in the following table:

Relation between weight and extract content for barleys of the same protein content.

Protein.	Number of samples.	Weight per 1,000 grains.	Extract.	Protein.	Number of samples.	Weight per 1,000 grains.	Extract.
Per cent.		*Grams.*	*Per cent.*	*Per cent.*		*Grams.*	*Per cent.*
10–10.8	2	28.0	72.6	12.0–12.4	5	27.5	71.8
	2	27.5	72.4		4	25.2	70.2
10.8–11	4	27.8	72.5	12.4–12.8	4	26.9	70.9
	3	26.7	71.5		4	25.0	69.5
11–11.2	5	28.0	72.4	12.8–13.2	4	27.8	71.0
	4	26.1	71.1		4	25.9	69.8
11.2–11.6	4	27.7	71.9	13.2–13.8	4	26.8	70.9
	3	24.5	69.8		3	26.3	69.1
11.6–11.8	5	27.8	71.8	Over 13.9	3	28.2	70.3
	4	25.0	70.6		4	26.4	66.0
11.8–12.0	4	27.3	72.1				
	4	25.5	70.6				

The figures show that a high-protein barley may give a high extract, provided the weight per 1,000 grains is large, and vice versa. The size of the grain affects, therefore, the quantity of extract, other factors being equal. This table also gives the relation between the protein and extract content, showing the natural tendency for high-protein barley to give less extract. There are, however, many individual exceptions to this rule, as was found by Prior [c] in his work on 2-row barley.

RELATION OF THE PROTEIN CONTENT TO THE CHARACTER OF THE ENDOSPERM.

Not only do the low-protein barleys weigh more per 1,000 grains and contain more extract, but they are much more mealy after steeping. For example, 31 samples of barley with an average protein content of 11.1 per cent have a coefficient of mealiness of 84, while 53 samples whose average protein content is 12.2 per cent have a coefficient of mealiness of only 80. This difference is accentuated if only those samples which contain over 12.2 per cent of protein are compared to those containing less than 11.25 per cent. In this case the former have a coefficient of mealiness of only 77 as compared with 87 for the latter.

Yet the actual number of flinty grains in the samples, before steeping, is about the same in each class, the high-protein samples containing 16 mealy and 43 steely grains per 100 and the low-protein barleys containing 15 per cent mealy and 44 per cent steely. The behavior

[a] Address at the meeting of Versuchs- und Lehranstalt für Brauerei, October, 1906.

[b] Wochenschr. Brau., 1906, **23**: 530.

[c] Loc. cit.

of these two classes of barley on steeping is, however, quite different. The steely and half-steely grains of the low-protein barleys are changed during this process to a greater degree than are those of high protein content. This fact is more definitely brought out by comparing the samples of high and low protein content after steeping. For example, 24 samples with more than 12.25 per cent of protein gave a coefficient of mealiness of 73.8, while 15 samples with less than 11 per cent of protein gave a mealiness coefficient of 87.8.

The same samples before steeping contained 17 per cent steely and 40 per cent mealy, with a coefficient of mealiness of 61.7, and 14 per cent steely, and 42 per cent mealy, with 64.1 coefficient of mealiness, respectively. These results show that permanent steely grains are richer in protein, and if not carefully malted they furnish steely malt and sinkers.[a] The high-protein barley underwent a 24 per cent modification on steeping, while the low-protein barleys were modified to the extent of 35 per cent. The estimation of the coefficient of mealiness is important only when made after steeping. As the high-protein barleys contain a larger percentage of steely grains and have a lower coefficient of mealiness than the low-protein barleys, it follows that steely grains contain less extract than do mealy ones. This is shown in the following table:

Ordinary 6-row barleys compared as to the character of the endosperm.

LESS THAN 75 PER CENT OF MEALY GRAINS AFTER STEEPING.

State.	Number of samples.	Extract.	Weight per 1,000 grains.	Degree of dissolution.	Coefficient of mealiness.	Protein.	Fat.	Starch.
		Per cent.	*Grams.*			*Per cent.*	*Per cent.*	*Per cent.*
Canada	3	71.7	26.9	68.5	74.5	12.0	1.95	59.2
South Dakota	4	69.2	24.0	71.5	75.5	13.3	1.72	58.2
Indiana	1	71.9	24.3	69.2	80.1	12.1	2.00	62.0
Iowa	2	70.1	24.9	51.3	64.7	12.6	2.05	57.1
Kansas	1	69.6	27.8	48.4	66.1	12.5	1.85	62.2
Michigan	2	71.6	26.5	61.0	75.0	11.4	1.97	59.1
Minnesota	11	70.7	26.0	72.7	78.2	12.2	2.02	58.9
Montana	3	68.8	23.8	67.9	76.6	12.6	2.20	60.1
New York	1	70.9	27.9	64.9	73.1	14.3	1.99	56.4
Wisconsin	19	71.3	27.2	74.3	78.0	12.0	2.03	58.8
Average	(47)	70.7	26.6	71.0	76.5	12.2	2.00	58.8

MORE THAN 75 PER CENT OF MEALY GRAINS AFTER STEEPING.

Colorado	1	72.1	28.8	80.3	83.0	11.7	2.07	56.8
South Dakota	1	69.5	24.1	95.2	92.0	12.4	1.76	62.4
Illinois	1	72.0	28.2	82.1	89.0	12.0	2.05	58.6
Iowa	5	70.7	24.7	103.6	91.3	11.4	2.00	59.0
Michigan	4	71.1	25.9	83.8	88.9	11.6	2.03	60.6
Minnesota	9	69.2	26.7	89.1	89.0	12.1	2.03	57.8
Wisconsin	15	72.1	28.7	95.2	89.0	11.4	1.98	59.8
Ohio	1	71.1	26.2	89.1	88.0	11.9	1.92	57.0
Average	(37)	71.0	27.1	92.4	86.5	11.6	1.99	59.2

[a] J. Brand, Zts. gesam. Brauw., 1906, **29**: 661.

The same relation of protein content to permanent and transitory steeliness is plainly shown by the following table, in which all samples examined are arranged in groups according to their protein content:

Effect of steeping on mealiness considered from the view point of protein content.

Number of samples.	Protein.	Degree of dissolution (Prior).	Coefficient of mealiness (Brown).		
			Before steeping.	After steeping.	Difference.
	Per cent.				
2	7.0– 7.5	107.7	31.00	98.75	67.75
1	8.0– 8.5	100.9	11.80	99.50	87.70
5	9.0– 9.5	108.4	36.65	96.31	59.66
6	9.5–10.0	92.8	11.66	94.26	82.60
6	10.0–10.5	90.7	22.47	90.69	68.22
13	10.5–11.0	87.3	31.61	87.39	55.78
20	11.0–11.5	82.4	33.55	83.51	49.96
20	11.5–12.0	84.3	34.26	84.44	50.18
13	12.0–12.5	73.6	34.35	78.82	44.47
13	12.5–13.0	66.7	31.15	75.12	43.97
6	13.0–13.5	60.6	32.09	70.71	38.62
7	13.5–14.0	67.9	33.23	74.47	41.24
1	14.0–14.5	64.9	29.59	73.19	43.60
3	14.5–15.0	62.9	47.12	71.14	24.02
1	15.0–16.0	54.3	44.85	69.58	24.73

The last column, which gives the difference between the coefficients of mealiness before and after steeping, indicates that as a general rule the more kernels are transformed into the mealy state by steeping, the less protein the barley contains. Both the degree of dissolution (Prior) and the coefficient of mealiness after steeping (Brown) increase with decreasing protein content; that is, the lower the protein content of a barley the more mealy in general its structure. If the figures for degree of dissolution be compared with those indicating the coefficient of mealiness (after steeping) it is seen that they are nearly identical for such barleys as are ordinarily used for malting purposes—that is, those containing from 10 to 13 per cent of protein—whereas beyond these limits the degree of dissolution rises or falls more rapidly than the coefficient of mealiness.

RELATION OF PROTEIN AND HULL CONTENT.

Prior[a] has also indicated that no connection exists between the protein and the hull content of barley. This may be true of 2-row barley, but when the 84 samples of 6-row barleys are examined one easily sees that with an increase in protein content there is also a corresponding increase in the percentage of hulls. Twenty-four samples of high-protein barleys (average, 13 per cent of protein) contain 12.9 per cent of hulls and 11.8 per cent of bran, while 23 samples of low-protein barleys (average, 10.9 per cent of protein) contain 12.4 per cent of hulls and 11.6 per cent of bran.

[a] Through Pure Products, 1907, 3: 92.

This may be due to the fact that the smaller grains contain relatively more protein than the larger ones, and of course the small grains contain relatively more hulls. Beaven[a] showed that small berries gave less extract, because they had a relatively larger amount of hulls.

COMPARATIVE COMPOSITION OF LARGE AND SMALL GRAINS.

One expects to find a rather close relation between the size of the grain and the amount of starch present. The difference, however, is really very slight, especially when the extreme cases are compared. For example, 20 samples the weight of which per 1,000 grains was over 28.5 grams have 58.6 per cent of starch, while 31 samples under 27 grams per 1,000 grains contain 58.8 per cent of starch. Johannsen's[b] results, showing that the big grains contain relatively less nitrogen than the small grains of the same variety, is also corroborated.

The percentage of embryo and bran in small and large grains varies little, but the results seem to show that small grains contain a lower percentage of endosperm than do the larger ones. Twenty samples with an average weight of 30.3 grams per 1,000 grains contain 72.5 per cent of endosperm, whereas 31 samples of smaller grains (average weight per 1,000 grains, 25.6 grams) contain 71 per cent.

There is also a relation between the size of the grain and the amount of hulls, the larger grains containing somewhat less hulls. This has also been found to be true by Wallerstein[c] and Beaven.[d]

Large grains contain more extract, starch, and endosperm than do the small ones. In 20 samples of 6-row barley, with a 1,000-grain weight above 28.5 grams, the percentage of bran is 11.8; hulls, 12.2; embryo, 2.5; endosperm, 72.5; extract, 71.7; starch, 58.6; and the weight per bushel is 49.5 pounds; while 31 samples of smaller grains of the same variety—that is, those weighing less than 27 grams per 1,000 grains—contain about 11.6 per cent of bran, 13 per cent of hulls, 2.53 per cent of embryo, 71 per cent of endosperm, 70.7 per cent of extract, 58.9 per cent of starch, and have a bushel weight of 46.6 pounds. The larger grains contain also less fiber, pentosans, and ash, but have a higher coefficient of mealiness. There is no appreciable difference in the fat, sulphur, or lecithin content in large and small grains. The weight per 1,000 grains varied from 19.9 to 33.5 grams. The weight per bushel varied from 42.5 to 51.5 pounds. The light grains are less plump, contain more nitrogen, and produce less extract. On the other hand, extra heavy grains are

[a] J. Fed. Inst. Brew., 1902, 8: 542.

[b] Compt. rend. travaux Carlsberg, 1899, 4: 122.

[c] Communications from Laboratory and Scientific Station for Brewing, Sec. Ann. Rep., 1904.

[d] Loc. cit.

richer in extract material, but, according to Prior, they malt less easily. The weight per bushel is not so important as is this weight taken in connection with the weight per 1,000 grains.

As has already been stated, the weight per bushel varies from 42.5 to 51.5 pounds, with an average of 46.7, the sample of lowest weight per bushel being from Montana and having also the lowest weight per 1,000 grains and a high percentage of nitrogen. This relation of high protein content to low bushel weight has been observed by many investigators, and almost invariably occurs when the sample has, for some reason, failed to develop normally and fully. It is a well-known physiological fact that the protein of cereals develops to a very large extent comparatively early in the life of the plant, whereas assimilation and the formation of carbohydrates may proceed as long as the leaves or stem contain any green coloring matter. If for any cause the plant fails to develop a plump grain it will naturally show not a larger amount of nitrogen but a relatively higher percentage. The barleys from Ohio and Illinois, which contain the lowest percentage of nitrogen, are characterized by being the heaviest. The weight per 1,000 grains likewise shows a very wide variation, 19.9 grams to 33.5 grams, with an average of 26.9 grams, the smaller grain showing a somewhat higher percentage of nitrogen.

OTHER CONSTITUENTS OF BARLEY.

The percentage of pentosans shows a variation from 8.31 per cent in Ohio-grown barley to 11.51 in the sample from South Dakota. These results indicate that a high content of hulls is accompanied by a high percentage of fiber and of pentosans, as would be expected, since grains with a high content of fiber generally yield the most pentosans, because of a rather close connection, not necessarily genetic, between fiber and pentosans.[a] High-protein barleys contain the most pentosans, on an average.

The percentage of fiber varies from 4.34 to 6.68, with an average of 5.76 for all samples. The average found by Clifford Richardson was only 4.08. These variations from one year to another are probably due to weather conditions. It may be interesting also to note that the sample grown in New York contained the least amount of hulls (only 10.17 per cent), while the one from Montana contained the largest amount (15.36 per cent). The high-protein barleys are somewhat richer in fiber than are the low-protein barleys, thus corroborating the researches of Bleisch and Regensburger.[b]

The percentage of fat in the barleys grown in the different States varied from 1.67 to 2.46, with an average of 2.02 per cent for all

[a] Calabresi, Staz. sperim. agrar. ital., 1906, **39**: 69.

[b] Zts. gesam. Brauw., 1905, **28**: 628.

samples. Richardson[a] states that the average of 10 samples was 2.87 per cent, considerably higher than that found in any of the present samples.

König[b] showed that the fat content of barley varied from 1.35 per cent, obtained in barleys grown in Württemberg, to 2.97, the latter representing the average of 16 Russian-grown barleys. There is no appreciable difference in fat content between high and low protein barleys. This corroborates Neumann's[c] results on 2-row barley.

The sugar results obtained in this investigation, though interesting, are unsatisfactory, owing to the fact that it was impossible to determine the sugar in the barleys until the samples were considerably over a year old. The barleys were harvested in the fall of 1904, and sent to the Bureau of Chemistry in the summer of 1905, soon after which most of the other determinations were made. In the fall and winter of 1905 the sugar determinations were begun. The results obtained were normal; that is, the invert sugar content varied from 0.8 per cent to 2.03 per cent, while the cane sugar varied from 1.02 per cent to 5.09 per cent. In February, 1906, while these results were being obtained, work had to be suspended temporarily and was not resumed until the following May, during which interim it was found that all of the invert sugar and most of the cane sugar had disappeared. This was true of both the ground and the unground barley. The cause of this phenomenon remains unknown, though it may be closely connected with the loss of diastase which takes place when seed has lost its germinating power.[d]

The percentage of ash in these 84 samples of barley averages 2.98 and varies from 2.5 to 3.5 per cent, a rather large variation, the Tennessee, Ohio, Illinois, and New York barleys containing less than those from the other States. On the other hand, Montana and Kansas barleys are very high in ash. No relation exists between the ash content and the percentage of protein. Delbrück[e] found that high and low protein barleys gave practically the same percentage of ash, fat, and hulls. The average ash content found in 79 samples of American barley, as quoted by König, is 3.10 per cent, a figure quite close to that obtained on the samples reported here.

The percentage of phosphoric acid varies from 0.8 to 1.25, increasing and decreasing as a rule with the amount of ash, in which the percentage of phosphoric acid varies from 27.4 to 42.1, the largest amount being found in Ohio. When extreme cases are taken into consideration there seems to be also a rather close relation between the amounts of phosphoric acid, protein, and starch present; the higher the per-

[a] U. S. Dept. Agr., Division of Chemistry, Bul. 9.

[b] Untersuchung landwirtschaftlich und gewerblich wichtiger Stoffe, p. 486.

[c] J. Inst. Brew., 1907, **13**: 87.

[d] Albo, through J. Inst. Brew., 1908, **14**: 405.

[e] Through Trans. Amer. Brew. Inst., 1905, **3**: 16.

centage of phosphoric acid the less protein and the more starch. This was true in over two-thirds of the samples examined. In this connection Richardson[a] found that phosphoric acid fertilizers increased the number of mealy grains, the effect being just the opposite to that of nitrogen fertilizers, which increase the flinty characteristics. It may thus be quite possible to decrease the protein content of barley by the liberal use of phosphate fertilizers; in other words, since it is fairly definitely known that nitrate fertilizers increase the protein content of grains, phosphates may be used to increase the starch content, thus producing a low protein barley. Kunz,[b] however, could find no relation between the amount of phosphoric acid and the extract yield.

The amount of sulphur varies in the 84 samples of barley from 0.15 per cent to 0.256 per cent, with an average for all of the samples of 0.182 per cent, following the protein content closely. As sulphur is a natural constituent of protein, it might be expected that a high-protein barley would contain more sulphur than one with low protein, and that this is the case was shown in over 80 per cent of the samples.

RELATION OF TOTAL TO SOLUBLE PROTEIN.

Regarding the soluble protein, the results indicate that the greater the total content of protein the smaller the percentage which is soluble; in other words, a larger proportion of the total protein is soluble in low-protein barleys than in high-protein barleys. The following table will show how general this relation is when the barleys are divided into groups according to their protein content:

Relation between the total and the soluble protein content of barley.

State.	Number of samples.	Protein content (below 11.49).		Number of samples.	Protein content (11.50–11.99).	
		Total.	Proportion soluble.		Total.	Proportion soluble.
		Per cent.	*Per cent.*		*Per cent.*	*Per cent.*
Canada				3	11.8	16.6
South Dakota				1	11.9	19.0
Iowa	4	11.1	19.2	1	11.6	19.6
Illinois	1	11.4	18.4			
Indiana				1	11.9	18.0
Michigan	3	11.1	18.0	2	11.8	17.3
Minnesota	5	10.9	17.6	4	11.9	18.5
Montana	1	11.4	19.2	1	11.6	17.0
Ohio				1	11.7	19.4
Wisconsin	18	11.0	17.6	5	11.6	17.7
Average	32	11.0	17.9	9	11.8	17.9

[a] U. S. Dept. Agr., Division of Chemistry, Bul. 9.

[b] Wochenschr. Brau., 1906, **23**: 530.

Relation between the total and the soluble protein content of barley—Cont'd.

State.	Number of samples.	Protein content (12–12.49).		Number of samples.	Protein content (over 12.50).	
		Total.	Proportion soluble.		Total.	Proportion soluble.
		Per cent.	*Per cent.*		*Per cent.*	*Per cent.*
New York				1	14.2	17.1
Colorado				1	12.5	15.7
South Dakota	2	12.3	17.8	2	13.7	16.3
Iowa	1	12.1	18.7	1	13.1	18.0
Michigan	1	12.2	17.3			
Kansas				1	13.4	13.1
Minnesota	8	12.3	18.0	3	12.9	18.5
Montana				1	14.9	16.8
Wisconsin	5	12.2	16.7	6	13.3	17.5
Average	17	12.2	17.0	16	13.4	17.1

In general, the 2-row barleys and the western barleys also show that a somewhat larger proportion of the protein is soluble in low than in high protein barleys (see p. 49). The same relation is true with respect to the malts also.

In the following table the samples of the Manchurian-Oderbrucker type are arranged in groups according to protein content and the averages of soluble and of soluble-coagulable protein given for each group. There is a small but distinct decrease of the percentage of soluble protein with increasing total protein, but there are many individual exceptions to this rule, especially in the case of the maximum and minimum figures obtained.

Relation between the soluble, the soluble-coagulable, and the total protein of some Manchurian-Oderbrucker barleys.

Total protein in barley.	Soluble protein (in terms of total protein).			Soluble-coagulable protein (in terms of soluble protein).
	Average.	Maximum.	Minimum.	
Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
10–11	16.8	17.8	15.4	27.9
11–12	16.7	19.1	14.6	29.7
12–13	16.5	19.6	14.0	28.7
13–14	16.0	18.6	14.8	29.1
14–15	15.4	15.7	15.1	31.7

As has already been noted, the amount of soluble nitrogen decreases with the increase of the total nitrogen; Wallerstein showed, however, that high protein and high soluble protein go together. This is not necessarily a contradiction, for in this study the percentage of soluble nitrogen was compared with the total nitrogen, while Wallerstein has only compared the percentage of total soluble nitrogen of high and low protein barleys.

Of the proteins in barley, therefore, from 81 to 85 per cent are insoluble. Of the soluble protein, about 30 per cent are coagulable. On

the other hand, Evans[a] finds that with 2-row barleys about 50 per cent of the soluble protein is coagulable, which is a much larger amount than that obtained in the work here reported on ordinary 6-row barleys.

LECITHIN IN ITS RELATION TO PROTEIN AND PHOSPHORIC ACID.

The amount of lecithin, or rather of alcohol-and-ether soluble bodies, varies from 0.39 to 0.69 per cent, with an average of 0.53 per cent, in accordance with the protein content. Stoklasa[b] found that seed containing the most protein likewise held a higher percentage of lecithin. This is substantiated by these data with but few exceptions; the amounts are, however, too small to make it possible to draw many conclusions.

There is no apparent connection between the amount of phosphoric acid in barley and the lecithin content, probably due to the fact that barley, like wheat, contains a larger proportion of a water-soluble organic phosphorus compound, similar to, if not, phytin, and that the amount of phosphorus found in barley is more nearly related to this more abundantly occurring body than to lecithin, the latter phosphorus compound being present in only relatively small quantities.

From the results given in Tables I and II it is seen that fully 35 per cent of the ash is composed of phosphoric acid compounds of which less than 5 per cent is in the form of lecithin phosphoric acid. The bulk of the phosphorus is present in the barley as a calcium-magnesium-potassium salt of oxymethylene diphosphoric acid, as was shown by Hart and Andrews,[c] who also showed that practically no inorganic phosphorus compounds existed in grains. The latter statement was afterwards corroborated by Schulze and Castoro,[d] and more recently Windisch and Vogelsang[e] established the same fact in regard to barley. There are several organic compounds of phosphorus existing in plants, chief among which, besides the previously mentioned compound, phytin, are the lecithin-like bodies, which have a glycerin radicle, and the nucleins, which are protein compounds containing phosphorus. Phytin occurs in quite large amounts, while the two latter compounds are present in smaller quantities.

Calcium, magnesium, and potassium, the more important ash constituents besides phosphorus, form on an average about 2.7 per cent, 7.3 per cent, and 23 per cent, respectively, of the total ash. There appears to be no appreciable difference in the amount of these constituents in the ash of low-protein barleys and high-protein barleys.

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[a] J. Inst. Brew., 1906, **12**: 209.

[b] Ber. deut. chem. Ges., 1896, **29**: 2761.

[c] New York Agr. Exp. Sta., Bul. 238.

[d] Zts. physiol. Chem., 1904, **41**: 477.

[e] Wochenschr. Brau., 1906, **23**: 516.

COEFFICIENT OF MEALINESS.

There is also a very noticeable difference in the degree of dissolution and in the coefficient of mealiness in these samples of barley. The former varies from 37 to over 117, while the latter shows a variation of from 55 to 98. Prior's method of determining the degree of dissolution very often gives values over 100. The coefficient of mealiness as determined by Brown gives somewhat lower results on low-protein barleys and higher results on high-protein barleys than Prior's degree of dissolution. The two methods are fairly indicative of the quality of barley. If the samples be arranged according to the percentage of mealy grains found after steeping, separating them into two classes, those with more than 75 per cent of mealy grains and those with less, it is seen (p. 39) that the lower protein content and the higher number of mealy grains go together. There is no difference in the fat content, but there is somewhat more starch in those samples containing the high percentage of mealy grains. The weight per 1,000 grains and the amount of extract are also greater in high than in low percentage mealy grains.

SUMMARY OF RESULTS.

ORDINARY SIX-ROW BARLEYS.

High-protein 6-row barleys contain a larger percentage of fiber, pentosans, hulls, bran, and embryo, but a smaller percentage of starch, extract, and soluble protein. The percentage of soluble protein that is coagulable is somewhat greater in high-protein than in low-protein barleys, but in the case of 2-row and Bay Brewing barleys there is no appreciable difference in this respect. The high-protein barleys weigh less per 1,000 grains and per bushel, besides having a lower degree of dissolution and coefficient of mealiness. This applies to all varieties of barley analyzed. No appreciable difference can be noted between high and low protein barleys in their content of fat, ash, sulphur, and lecithin, as is shown in the following tables, which also show no difference in the percentage of steely grains before steeping between barleys of more than and less than 11.5 per cent protein, when these are averaged. However, if the extreme cases—that is, those samples containing more than 12.25 per cent protein—are compared with barleys of less than 11 per cent protein, we find that the former contain 10 per cent steely and 63 per cent mealy grains after steeping, while the latter have only 4 per cent steely and 77 per cent mealy, thus clearly showing that the barleys with over 12 per cent protein are not so easily altered by the process of steeping as are low-protein barleys.

Comparison of ordinary 6-row barleys of high and low protein content.

MORE THAN 11.5 PER CENT PROTEIN.

State.	Number of samples.	Fat.	Fiber.	Pentosans.	Starch.	Ash.	Sulphur.	Phosphoric acid.	Calcium oxid.	Magnesium oxid.	Potassium oxid.	Lecithin.	Hulls.	Bran.	Embryo.	Endosperm.	Weight per 1,000 grains.	Extract.	Weight per hectoliter.	Degree of dissolution.	Coefficient of mealiness.	Before steeping.		In total protein.		
																						Mealy.	Steely.	Soluble protein.	Sol. coag. protein in water sol.	Protein.
		P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*Gms.*	*P. ct.*	*Kilos.*			*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
Canada	3	1.95	5.65	9.66	59.22	3.03	0.193	1.09	0.09	0.19	0.73	0.50	11.89	11.5	2.5	73.4	26.88	71.66	61.6	68.5	74.7	10	59	16.6	28.3	12.0
South Dakota	5	1.93	6.13	10.76	59.02	2.95	.182	.90	.06	.21	.67	.56	33.6	11.9	2.6	71.1	24.03	69.32	59.1	76.2	79.1	20	34	16.6	24.4	13.1
Illinois	1	2.05	5.82	9.31	58.57	2.76	.160	1.16	.06	.21	.72	.43	12.4	13.9	2.6	73.5	28.2	72.0	65.4	8.21	89.0	4	72	17.5	31.2	12.0
Indiana	1	2.00	6.38	9.50	61.97	3.09	.187	.98	.07	.30	.76	.60	12.5	11.3	2.4	70.7	24.3	71.9	60.3	69.2	80.1	5	70	14.8	33.3	12.1
Iowa	4	2.10	6.25	10.55	57.97	3.03	.187	.98	.08	.21	.68	.50	13.3	11.6	2.7	71.0	25.2	70.9	61.3	79.9	80.5	20	39	17.5	27.5	12.2
Kansas	1	1.85	6.46	8.79	62.25	2.97	.198	.98	.07	.29	.71	.52	13.8	11.8	2.4	72.8	27.8	69.6	58.7	48.4	66.2	3	87	15.0	30.3	13.4
Michigan	1	2.09	5.24	9.01	65.42	2.97	.171	1.01	.07	.20	.71	.55	13.5	10.7	2.7	72.3	24.5	71.2	62.8	85.8	89.5	6	59	15.1	26.8	12.8
Minnesota	14	2.01	5.96	9.77	58.47	3.03	.185	1.07	.08	.21	.72	.53	12.6	11.9	2.5	72.0	26.2	70.6	60.0	77.0	81.6	12	47	16.6	29.0	12.6
Montana	2	2.25	5.90	9.95	58.90	3.45	.200	1.17	.09	.26	.77	.70	13.5	11.3	2.3	69.0	21.4	67.9	57.3	68.6	76.3	16	35	15.8	30.1	13.2
New York	1	1.99	5.31	9.28	56.38	2.75	.231	1.00	.10	.19	.72	.58	10.2	11.4	2.7	74.2	27.9	70.9	61.3	64.9	73.1	11	53	15.1	30.1	14.3
Colorado	1	2.07	5.69	10.03	56.77	2.79	.159	1.41	.07	.30	.69	.52	12.3	13.4	2.3	71.9	29.3	72.1	64.8	80.3	83.0	14	27	15.7	31.5	12.5
Wisconsin	18	2.02	5.61	9.33	58.77	2.95	.178	1.09	.08	.23	.72	.51	12.3	11.5	2.6	72.1	27.7	70.7	61.0	80.1	80.7	21	36	16.5	32.3	12.5
Ohio	1	1.92	5.63	8.31	57.01	2.78	.179	1.17	.....	.....	.....	.41	14.0	11.4	2.6	71.2	26.2	71.1	64.8	89.1	88.0	15	40	15.9	29.5	11.9
Average	(53)	2.02	5.61	9.70	58.66	3.01	.183	1.06	.08	.22	.73	.51	12.3	11.6	2.6	72.0	26.9	70.6	60.7	77.1	80.2	16	43	16.5	29.9	12.2

LESS THAN 11.5 PER CENT PROTEIN.

Iowa	3	1.89	5.91	10.5	59.1	3.0	.17	1.00	.08	.23	.69	.47	12.8	11.8	2.7	72.7	24.2	70.0	60.3	100.9	91.4	21	38	16.5	24.7	11.2
Michigan	5	2.02	5.58	9.5	59.0	2.9	.18	1.03	.10	.22	.69	.57	12.0	11.5	2.7	71.9	26.3	71.2	60.2	74.3	83.2	4	66	17.0	28.6	11.3
Minnesota	6	2.05	5.80	9.7	58.9	2.9	.17	1.07	.08	.20	.69	.50	12.7	12.0	2.5	72.3	26.4	71.3	61.4	80.8	77.7	15	42	17.2	27.7	11.1
Montana	1	2.10	5.40	8.8	62.5	3.3	.20	1.10	.09	.24	.75	.65	11.2	11.7	2.7	71.8	28.4	70.6	62.3	66.7	77.1	8	58	18.8	27.1	11.4
Wisconsin	16	2.00	5.60	9.4	59.9	3.0	.18	1.07	.08	.22	.70	.51	12.3	11.5	2.5	72.6	27.9	72.6	61.6	87.0	85.4	17	38	16.7	29.2	10.9
Average	(31)	2.00	5.66	9.56	59.6	2.96	.18	1.06	.08	.22	.70	.52	12.3	11.6	2.5	72.4	27.0	71.8	61.2	84.4	83.8	15	44	16.9	28.4	11.1

The following table likewise shows the difference in coefficient of mealiness, degree of dissolution, percentage of extract, etc., between high and low protein barleys:

Comparison of high and low protein barleys.

TWO-ROW.

State.	Number of samples.	Degree of dissolution.	Coefficient of mealiness.	Protein.	Weight per thousand.	Weight per bushel.	Extract.	Soluble protein.	Coagulable protein in water-soluble
OVER 11.5 PER CENT OF PROTEIN.				*Per cent.*	*Grams.*	*Pounds.*	*Per cent.*	*Per cent.*	*Per cent.*
California	1	62.0	77.6	12.9	32.6	52.7	74.0	14.3	32.4
Colorado	5	48.7	54.3	13.2	41.6	51.0	71.4	15.8	32.8
New York	1	77.8	83.5	12.6	31.3	50.2	72.7	16.5	31.8
South Dakota	1	50.0	68.1	11.6	28.3	48.5	69.4	17.7	21.8
Kansas	1	77.1	79.1	17.4	34.7	47.2	69.4	15.4	34.9
Average	9	56.7	64.4	13.4	37.2	50.4	71.4	16.0	31.6
UNDER 11.5 PER CENT OF PROTEIN.									
California	1	116.9	97.5	9.3	38.0	49.5	73.9	15.8	28.8
Germany	1	100.8	98.0	9.5	47.6	55.7	79.1	15.2	30.3
Canada	1	77.2	87.0	10.8	38.1	50.5	74.2	18.4	31.3
Idaho	1	85.0	91.0	11.0	37.5	52.5	73.7	15.4	31.8
Montana	5	116.4	97.6	10.0	38.9	55.0	76.4	19.0	32.3
Average	9	95.7	95.7	10.1	39.5	53.7	75.9	17.6	31.5

BAY BREWING BARLEY (6-ROW).

OVER 11.5 PER CENT OF PROTEIN.									
California	2	39.4	61.0	13.2	32.0	40.3	68.3	13.5	25.4
Oklahoma	1	54.3	69.6	15.8	28.0	39.2	62.9	20.3	33.7
Kansas	1	79.6	81.1	13.6	29.7	40.0	68.4	14.9	25.8
Tennessee	2	55.4	66.2	12.2	28.5	45.7	71.4	15.5	31.3
Average	6	53.9	67.5	13.4	29.8	41.9	68.5	15.5	28.8
UNDER 11.5 PER CENT OF PROTEIN.									
California	6	100.7	96.2	9.1	36.4	46.5	71.8	15.4	27.7
Idaho	3	96.2	96.8	10.1	40.0	46.7	72.2	16.3	29.9
Washington	3	97.6	97.5	10.0	40.8	47.2	72.3	16.2	29.4
Average	12	98.8	96.6	9.5	38.4	46.7	72.0	15.8	28.7

The great variations in the composition of these 84 samples of 6-row barleys, which belong practically to the same variety—that is, Manchurian—and which have been grown in widely separated localities differing from one another in soil and general climatic conditions, again demonstrate how great is the influence of environment on the composition of plants. There is a greater difference in the composition and in the physical characteristics of the barleys of the same type grown in different localities than there is between different varieties grown in the same environment. This is well illustrated in Tables I and II, which give the average composition of the four varieties of barley. There seems to be a greater influence exerted by climate than by seed, variety, or difference in soil characteristics. Ac-

cording to König,[a] a barley grown in a sandy soil, a clay soil, and a soil rich in lime differed in protein content as follows: 11.1, 13.4, 12.7. Much larger differences than these are obtained by growing the same varieties in different localities. Eckenbrecher[b] likewise has recently shown that there is a greater difference in composition and physical characteristics of barley of the same type grown in different localities than of different varieties grown in the same locality. The same has been shown by Kiessling[c] and others.

TWO-ROW BARLEYS.

No attempt will be made to draw conclusions of this character from the data here presented on 2-row, Utah Winter, or Bay Brewing barleys, because of the fact that comparatively few samples of each variety were analyzed. In general, however (Table II), it is readily seen that the percentage of protein is very slightly lower in the 2-row barleys than in the 6-row barleys (Table I) of the Manchurian type, the average in the former case being about 11.6 per cent. The five samples from Montana average less than 10 per cent. Although the 2-row barleys do not contain much less protein than do the 6-row, there appears to be somewhat less fiber, pentosans, ash, sulphur, hulls, embryo, and steely grains, but more starch, extract, soluble albumen, bran, and endosperm, a higher coefficient of mealiness and degree of dissolution, and a greater weight per 1,000 grains and per bushel in the 2-row than in the 6-row barleys. The other constituents show no great variation between the two types of barley. A striking difference between 2-row and 6-row barleys is found in the fact that the former contain a larger proportion of bran than of hulls, while in the latter the percentage of hulls is greater than the percentage of bran. The western 6-row barleys are in this respect similar to the ordinary 6-row barleys.

SIX-ROW WESTERN BARLEYS.

Twenty-seven samples of 6-row western barleys were analyzed. They are usually called Bay Brewing barley or Utah Winter, the former being characterized by their thick skin and the latter by their somewhat thinner hulls. Both varieties are large. Compared with the ordinary 6-row barleys, they show a closer resemblance to them in chemical composition than do the 2-row barleys. They are, however, much larger, weigh more per bushel, and contain less protein (somewhat less than the 2-row barleys). They contain a slightly larger percentage of hulls, but less total sulphur and soluble protein than do other 6-row barleys. The average weight per 1,000 grains of 6-row barley is less than 27 grams, compared with 36 grams

[a] Untersuchung landwirtschaftlich gewerblich wichtiger Stoffe, p. 517.
[b] Wochenschr. Brau., 1907, **24**: 491.
[c] Loc. cit.

as the weight per 1,000 grains of western barleys. There is a very close agreement between the two varieties in the content of ash, fat, fiber, bran, pentosans, starch, and ash constituents.

COMPARISON OF MALTS.

Thirty malts were prepared from the ordinary 6-row barleys, 8 from the western barleys (Bay Brewing and Utah Winter), and 5 from 2-row barleys.

In comparing the composition of malts made from these three different varieties of barley, Table III shows that 6-row malts contain a larger percentage of the following constituents: Sulphur, lecithin, total protein, soluble protein, soluble noncoagulable protein, and embryo; a smaller percentage of starch, of extract in fine and coarse grist, and of bran; a smaller weight per bushel and per 1,000 grains, and a smaller coefficient of mealiness. Two-row malts, on the other hand, are higher in endosperm, weight per bushel, extract in fine and coarse grist, and coefficient of mealiness, and lower in fiber, pentosans, hulls, and embryo. The large western malts—the Bay Brewing and Utah Winter—are higher in hulls and lower in sulphur, protein, soluble protein, and soluble noncoagulable and coagulable protein. There is very little difference between the varieties in the percentage of ash, phosphoric acid, and fat. The western malts resemble those of the ordinary 6-row barleys in the amount of fiber, pentosans, hulls, bran, embryo, endosperm, and starch which they contain. They are somewhat like the 2-row malts in weight per bushel, weight per 1,000 grains, and in the per cent of total protein.

The following table shows how high and low protein malts compare in weight per 1,000 grains, per cent of extract in fine grist, weight per hectoliter, per cent soluble protein and per cent coagulable protein, the per cent mealiness, and coefficient of mealiness. On an average, the high-protein malts are much less mealy in the case of all three classes of malt. The coefficient of mealiness is also less, as are also the weight per 1,000 grains, the per cent of extract, and the per cent of soluble protein.

Comparison of high and low protein malts.

State.	Number of samples.	Protein.	Mealy.	Coefficient of mealiness.	Weight per 1,000 grains.	Extract of fine grist.	Weight per hectoliter.	Soluble protein in total protein.	Coagulable protein.
OVER 11.5 PER CENT OF PROTEIN (6-ROW).		*Per ct.*	*Per ct.*		*Grams.*	*Per ct.*	*Kilos.*	*Per ct.*	*Per ct.*
South Dakota	1	13.3	71	80.0	21.0	71.7	46.7	38.0	3.7
Illinois	1	12.1	95	97.0	24.9	72.6	45.4	36.8	4.8
Iowa	1	13.0	76	79.7	22.7	72.1	45.8	37.6	3.2
Michigan	1	12.6	76	85.1	21.4	71.5	48.0	33.4	3.5
Minnesota	5	12.3	76	84.4	24.5	73.5	48.2	36.7	4.0
Ohio	1	11.5	78	84.6	23.3	72.9	.....	41.3	3.4
Wisconsin	7	12.5	80	90.4	24.7	73.4	44.3	35.3	3.4
Colorado	1	11.6	60	76.1	28.3	73.2	51.3	29.4	5.9
Average	18	12.5	80	86.6	24.0	73.1	47.0	36.4	3.8

Comparison of high and low protein malts—Continued.

State.	Number of samples.	Protein.	Mealy.	Coefficient of mealiness.	Weight per 1,000 grains.	Extract of fine grist.	Weight per hectoliter.	Soluble protein in total protein.	Coagulable protein.
UNDER 11.5 PER CENT OF PROTEIN (6-ROW).		*Per ct.*	*Per ct.*		*Grams.*	*Per ct.*	*Kilos.*	*Per ct.*	*Per ct.*
Michigan	2	11.2	91	95.0	25.9	75.7	48.7	37.0	4.0
Minnesota	4	11.1	78	86.0	23.7	72.0	47.0	37.6	5.2
Wisconsin	7	11.3	94	96.4	25.0	73.9	46.7	37.8	4.6
Average	13	11.2	89	93.0	24.7	73.6	47.1	37.6	4.7
OVER 11.5 PER CENT OF PROTEIN (2-ROW).									
New York	1	13.8	60	73.6	22.7	72.9	48.7	35.6	4.5
UNDER 11.5 PER CENT OF PROTEIN (2-ROW).									
Montana	4	9.6	96	97.7	33.5	78.7	53.1	38.0	4.3
OVER 11.5 PER CENT OF PROTEIN (BAY BREWING AND UTAH WINTER).									
Washington	1	12.3	68	81.6	35.1	71.8	50.0	32.2	3.6
UNDER 11.5 PER CENT OF PROTEIN (BAY BREWING AND UTAH WINTER).									
California	2	8.2	90	93.0	34.0	72.0	45.4	38.3	3.6
Idaho	2	10.1	91	95.0	32.9	72.6	46.3	32.3	3.3
Utah	1	10.9	65	77.6	32.8	73.9	48.7	32.3	4.0
Washington	1	8.3	93	97.5	34.5	77.2	48.7	35.6	3.5
Montana	1	9.5	86	91.5	32.3	75.3	45.4	36.3	3.9
Average	7	9.3	87	91.8	33.4	73.6	46.6	35.1	3.5

The hulls of 6-row malt form a much larger percentage of the grain than do the hulls of 2-row malts, and yet the protein content of the 6-row barley is 1.5 per cent higher than that of the 2-row variety. These two factors only emphasize how much smaller the percentage of carbohydrates must be in 6-row than in 2-row barley malts.

Malts are sometimes rejected by brewers because of a high bushel weight. The following table will show that this factor is absolutely useless when considered alone, for very often those malts having a high bushel weight will give a larger yield of extract in the coarse grist than malts of lower weight per bushel.

Comparison of weight per bushel and yield of extract.

Kind of malt.	Number of samples.	High weight per bushel.	Extract.	Number of samples.	Low weight per bushel.	Extract.
		Pounds.	*Per cent.*		*Pounds.*	*Per cent.*
2-row malt	4	41.25	76.7	2	36.5	70.6
6-row Bay Brewing malt	4	38.25	70.1	4	35.6	69.9
6-row Manchurian malt	15	37.7	70.5	12	35.6	69.9

As Wallerstein[a] has shown, a high bushel weight of malt is no more an indication of inferiority than is the low weight per bushel a

[a] Communications from Laboratory and Scientific Station for Brewing, Sec. Ann. Rep., 1904.

proof of its superiority. This clearly shows that one factor alone, and especially the bushel weight, is not enough to determine the value of a malt. Again, many times, even when this factor is considered in connection with the weight per 1,000 grains, there are not sufficient data at hand to warrant a rejection of the malt, for the following table will illustrate how it is possible to have malts whose bushel weights are high, but whose weights per 1,000 grains are low, and yet the extract yield is higher than the average. On the other hand, some malts with a high weight per 1,000 grains and a high bushel weight give a yield of extract lower than the average. The average weight per 1,000 grains of malts of high bushel weight and of high yield of extract is very little higher than in the case of low bushel weight.

Comparison of 6-row malts having a high and a low weight per bushel.

High weight per bushel.			Low weight per bushel.		
Weight per bushel.	Weight per 1,000 grains.	Extract.	Weight per bushel.	Weight per 1,000 grains.	Extract.
Pounds.	*Grams.*	*Per cent.*	*Pounds.*	*Grams.*	*Per cent.*
38.75	25.9	74.1	36.25	21.0	68.8
36.75	26.0	70.8	35.25	24.9	71.5
37.25	21.4	68.5	35.50	22.7	67.5
36.50	24.7	63.6	34.25	22.1	69.8
38.50	24.8	71.6	36.00	25.3	68.2
40.50	24.6	70.0	35.75	24.6	70.7
37.50	23.0	69.3	36.00	24.3	71.8
37.50	23.3	71.0	35.75	25.1	73.0
38.00	25.0	70.8	36.00	25.0	69.1
37.00	25.1	71.9	35.25	25.5	70.6
37.00	25.0	72.5	36.25	24.0	66.0
37.75	24.8	70.0	34.75	22.7	71.9
36.50	25.4	68.3			
38.00	27.3	70.9			
37.50	23.4	70.8			
37.7	24.6	70.5	35.6	23.9	69.9

As a general rule, however, a malt with a high weight per bushel will give more extract and will weigh more per 1,000 grains than a malt with low weight per bushel. The following figures selected from the preceding table plainly show this:

A comparison of the extremes of weight per bushel with yield of extract.

Over 37.7 pounds per bushel.		Less than 35.6 pounds per bushel.	
Weight per 1,000 grains.	Extract.	Weight per 1,000 grains.	Extract.
Grams.	*Per cent.*	*Grams.*	*Per cent.*
25.9	74.1	24.9	71.5
24.8	71.6	22.7	67.5
24.6	70.0	22.1	69.8
25.0	70.8	25.5	70.6
24.8	70.0	22.7	71.9
27.3	70.9		
25.4	71.2	23.5	70.2

But it is not always enough to know the weight per bushel and the weight per 1,000 grains in order to properly select malt. One should also determine other factors, such as mellowness, percentage of germination, water, protein, and extract, the color, odor, impurity, and the diastatic power, etc., basing the decision on all of these results.

From the entire study it is very evident that the variation in climatic conditions throughout the country, the difference in soil, the different methods of cultivation and rotation practiced—all have their bearing on the characteristics of barley, and from the great variation in composition it is safe to assume that the United States can produce barley of the first rank, whether 6-row or 2-row varieties be grown. As the climate varies greatly from one locality to another, and such conditions exert the greatest influence on the quality of the crop, care should be taken to select the seed and locality according to the type of barley desired. For example, moist climates and localities where plants have long periods of growth, especially between the stage of flowering and maturity, generally produce a low-protein barley. In such localities it would generally be impossible to grow barleys rich in protein.

CHANGES IN COMPOSITION DURING MALTING.

One of the most interesting and instructive series of results obtained in this work relates to the changes which each constituent of the barleys underwent during malting. This is shown in Table IV. These figures were obtained by analyzing the malts, and then calculating the malt analyses to the basis of the corresponding barleys by multiplying the results of the malt analyses by the factor obtained by dividing the weight of 1,000 grains of malt by that of 1,000 grains of barley. This factor averages about 89, but as a rule the factor found by actually weighing the barley and the amount of malt obtained therefrom on a laboratory scale was used. In several cases, however, the factor 89 was used in the conversion of the malt figures to the basis of the barley. This was the case wherever the results showed that an apparent error had been made, or where a sample of either the malt or barley had been lost before the weight per 1,000 grains was obtained. The loss in malting a barley is due to the loss of soluble constituents and respiration of carbonic acid and to the formation of the radicles. On the other hand, there is a slight gain in weight due to the fixation of water during the conversion of starch to sugar, and possibly also to the hydrolysis of the proteins.[a] The losses on malting were then calculated by dividing the difference between the percentage of each constituent in the barley and in the malt (calculated to the barley basis) by the percentage of that constituent in the barley itself.

[a] Long, J. Amer. Chem. Soc., 1907, **29**: 295.

In this way the following changes due to malting were estimated, the figures given being the average of the results obtained from the analyses of 43 samples of barley and of their corresponding malts:

Loss and gain in the various constituents of barley due to malting.

Constituent.	Gain or loss.	Constituent.	Gain or loss.
	Per cent.		*Per cent.*
Fat	− 7.7	Sulphur	+ 9.0
Fiber	− 8.4	Lecithins	+ 34.3
Pentosans	− 1.6	Hulls	− 8.5
Starch	− 28.0	Bran	− 37.0
Reducing sugars as invert sugar	+400.0	Embryo	+ 78.7
Cane sugar	+ 71.0	Endosperm	− 10.2
Ash	− 20.7	Total protein	− 12.0
Potassium oxid	− 48.0	Soluble protein	+ 72.5
Calcium oxid	− 22.0	Soluble-noncoagulable protein	+104.0
Magnesium oxid	− 17.0	Soluble-coagulable protein	+ 13.0
Total phosphoric acid	− 12.7		

Although it should not be assumed that these results represent exact amounts, yet they indicate fairly well the changes going on during malting. From these averages it is seen that when barleys are malted they lose appreciably in fat, lime, magnesia, phosphoric acid, hulls, protein, fiber, and endosperm. There is a greater loss, however, in starch, ash, bran, and potash. No appreciable loss is noted in pentosans, while on the other hand there is a considerable gain in the amount of lecithin and soluble coagulable protein, and a very large increase in sugars, embryo, soluble protein, and soluble noncoagulable protein.

The loss of the different constituents is, of course, due to the growth of the acrospire and rootlets or malt sprouts, to the amount of respiratory products produced during this growth, and to the various physiological changes; for example, the conversion of starch into maltose, etc. Thus, much of the starch (over 20 per cent) has been lost during malting, but most of this loss is made up by the corresponding gain in sugars. A part of the sugars produced from this starch and some of the fat were given off as carbon dioxid produced by respiration during the malting. Another part of the starch conversion products was transferred to the malt sprouts, the insoluble and therefore the immovable starch having first been converted by the diastase into soluble and transferable sugars, which then migrated to the sprouts. These sprouts are likewise rich in phosphoric acid and other salts containing over 1.5 per cent of phosphoric acid alone, besides over 3 per cent of potash and an appreciable amount of lime and magnesia. This partly accounts for the large loss of ash, phosphoric acid, and other constituents, and also of the bran of barley during malting. As one can readily see, the loss of phosphoric acid, of ash, and of bran are closely related, being, respectively, 12.7 per cent, 20.7 per cent, and 37 per cent. The ash not only lost phosphoric acid but also some of all of the other constituents, namely,

48 per cent of potash, 22 per cent of lime, and 17 per cent of magnesia. This explains why the loss of ash is greater than that of phosphoric acid. According to König,[a] barley bran contains about 7 per cent of ash, of which 50 per cent is phosphoric acid. That fact explains why such a loss in bran takes place during the process of malting barley. A large portion of the ash lost, consisting of phosphoric acid and other salts, would naturally come from the bran, which constituent of barley is richest both in ash and in phosphoric acid. The protein lost during malting is, of course, to be found chiefly in the malt sprouts. In order to be thus transported from the barley grain to the malt sprout, the insoluble protein had to be made soluble by the proteolytic enzymes which are always present in grains and only await propitious conditions in order to become active. The insoluble protein, having been converted into soluble and movable protein, and possibly also having been changed into the amid form, migrates to the growing plantlet and rootlet and again becomes insoluble and fixed, just as the starch first becomes soluble before it can migrate, and through physiological processes again becomes insoluble in forming cellulose for the cell walls, etc. It should be noted that high-protein barleys lost on an average over 16 per cent of the total nitrogen, while the low-protein barleys lost about 11 per cent on malting, the former losing considerably more starch also during this process.

Analysis of the sprouts or rootlets obtained from malted barley showed that they contained about 5 per cent of the total phosphoric acid, 20 per cent of the potash, and from 2 to 3 per cent of the lime and magnesia found in the malt. The difference between the total loss observed in malting and the above figures shows the amount of these constituents actually lost on steeping.

Brown and Morris [b] show that in malting there is an increase of over 300 per cent of cane sugar in the embryo and a still larger increase in the endosperm, besides which a large amount of maltose is found in the malt endosperm, having been produced from the starch of the barley endosperm. Similar results were obtained by O'Sullivan [c] long before in his masterly researches on sugars. Delbrück [d] quotes Grüss and Schönfeld's work showing that despite the fact that enzyms are breaking down the starch into sugar during malting, a considerable reconversion of starch from the sugar takes place, especially during the drying of the malt. Hoffmann and others (see Delbrück) showed that the drying of malt likewise changed amids into protein. This has led to a comparison of the physiological process taking place

[a] Untersuchung landwirtschaftlich und gewerblich wichtiger Stoffe, p. 771.
[b] Text-book of Science of Brewing, p. 74.
[c] J. Chem. Soc., 1886, **49**: 58.
[d] J. Inst. Brew., 1906, **12**: 644.

during the drying of the malt with that occurring during the ripening of grains. Some work carried on in the Bureau of Chemistry on the changes in sugar and soluble nitrogenous constituents during malting and during the drying of the malt have failed to fully corroborate the above conclusions relating to the conversion of sugar into starch. The results show, on the dry basis, the following amounts of sugar (calculated as dextrose): Barley soaked two days preparatory to malting, 1.16 per cent; green malt, 6.14 and 7.25 per cent; and malt (dried one day at 35° C.), 8.3 and 11.47 per cent. An increase rather than a decrease in sugar has evidently taken place during the first day's drying, due probably to the fact that the slow drying at 35° C. with the large initial amount of moisture in the green malt was really a continuation of the malting process which continued until the moisture content became too low, due to evaporation, to carry this process any further. A slight decrease of sugar, however, is noted at the end of a month, 10.01 per cent being present in the sample which on the first day's drying contained 11.47 per cent. This work is being repeated.

Our results further show that practically no change has taken place in the pentosans during malting. Tollens and Glaubitz[a] showed that the pentosan content of both barley and malt was the same, no change having taken place during the malting process. It is quite probable, however, that the carbohydrates necessary for the growth of the sprouts and for respiration during seed growth are furnished entirely or mostly by the more assimilable constituents, namely, the sugars normally present and those produced by the action of the diastase on the starch and also by the fat.

The sulphur content increased perceptibly, according to these results. This simply means, however, that some malts had been bleached by the use of sulphur, or else had absorbed some sulphur compounds from the products of combustion during the kilning process. In any case there has not been and there could not have been any real increase in the amount of sulphur unless the malts had absorbed it in some such manner.

It is quite different, however, with the increase of lecithin, or rather alcohol and ether-soluble phosphorus compounds. Here we are dealing with a body, or several phosphorus-containing bodies, which are soluble in both alcohol and ether or in one of these reagents. The active physiological changes going on in the barley during malting have already been noted in so far as the losses in ash, phosphoric acid, and bran are concerned, and it is quite probable that some of the phosphorus compounds of barley, which are insoluble in alcohol and ether, go through some of these changes and become soluble in

[a] J. Landw., 1897, 45: 106, through Principles and Practice of Brewing, Sykes and Ling.

these reagents. That such is the case the results here reported would seem to indicate. Windisch[a] has already shown that the phosphoric acid compounds of barley undergo a very great change in malting, the organic phosphorus being to a large extent hydrolyzed and converted to the inorganic condition. It is quite probable that some of this same organic phosphorus of barley, which is soluble in water, also changes into another form of organic phosphorus which is soluble in alcohol and ether.

The great increase in sugar is easily explained from the effect of the diastatic action on starch.

The growth of the embryo during germination is a natural one. At the full malt period it has increased nearly 100 per cent, the variation being from 38 to 209 per cent. This variation is because of the fact that some grains begin to germinate and then stop, the length of the acrospire being less than one-fourth of that of the grain itself, whereas in a good malt its growth should be from three-fourths to one.

That a most active proteolytic action took place in the barley during malting is clearly indicated by the increased amount of soluble protein. Whereas the total protein suffered a loss averaging 12 per cent, the amount of soluble protein increased over 70 per cent, thus showing that even as a very active diastatic action was noted by the conversion of the starch into sugar, so an almost equally active physiological change due to the proteolytic enzym was being brought about in regard to the protein of barley. Similar results have been obtained by Brown[a] and Evans.[b]

The results given in the following table show the relative amounts of water-soluble proteins in high and low protein malts, and likewise the amount of protein rendered soluble on mashing and found in the wort:

Comparison of soluble protein and proteins dissolved by mashing.

HIGH-PROTEIN MALTS (6-ROW).

Laboratory No.	Protein in malt on barley basis.	Protein dissolved on mashing.		Soluble protein based on total protein.	
		Based on total substance.	Based on total protein.	In barley.	In malt on barley basis.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
102	11.0	5.08	46.2	16.1	35.3
91	11.4	4.89	42.8	18.0	36.0
58	11.3	4.21	37.2	17.3	31.0
111	11.3	4.41	39.0	18.4	36.0
59	10.7	4.67	43.6	18.4	40.0
51	10.3	4.44	43.1	17.4	36.7
71	11.1	5.30	47.7	17.9	35.1
73	10.5	4.91	46.7	17.4	41.3
84	10.7	4.35	40.6	18.2	37.4
12	11.3	5.65	50.0	17.1	30.2
Average	11.0	4.79	43.7	17.6	35.9

[a] Loc. cit.

[b] J. Inst. Brew., through the Wahl-Henius "Handybook," pp. 426–433.

Comparison of soluble protein and proteins dissolved by mashing—Continued.

LOW-PROTEIN MALTS (6-ROW).

Laboratory No.	Protein in malt on barley basis.	Protein dissolved on mashing.		Soluble protein based on total protein.	
		Based on total substance.	Based on total protein.	In barley.	In malt on barley basis.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
16	10.2	3.40	33.3	15.7	30.0
46	9.5	4.15	43.7	17.6	35.9
53	9.6	4.12	42.9	18.0	39.0
104	9.8	3.96	40.5	19.1	35.5
115	9.5	3.89	40.9	18.0	35.8
37	9.6	3.52	36.8	18.1	42.1
22	8.0	4.19	52.2	17.9	35.0
35	9.8	4.45	45.4	17.5	37.9
32	9.8	4.36	43.6	16.9	35.5
Average	9.5	4.01	42.4	17.7	36.3

The figures show a somewhat higher percentage of protein dissolved on mashing in high-protein malts, as Wallerstein [a] has already shown, also that somewhat more protein (10 to 15 per cent) is rendered soluble on mashing than by simple treatment with cold water.

Kunz [b] showed that from 25 to 41 per cent of the protein was found in the extract, a somewhat larger amount of the nitrogen being rendered soluble in the high-protein malt, or small-grain malt, due to the greater activity of the enzyms present.

The loss of total protein during malting has averaged about 12 per cent when all of the samples, 2-row, 6-row Bay Brewing, and ordinary 6-row Manchurian are taken together. By separating the malts which were made from high-protein barley from those obtained from the low-protein barley it is shown that the first-named barleys suffer a greater loss of protein on malting than do the latter; for example, 10 samples of barley with high-protein content underwent an average loss of total protein in malting of 16 per cent, whereas the corresponding loss from 19 samples of low-protein barleys was 12 per cent.

The work done on the comparative composition of barley and malt shows that about one-fifth of the ash constituents of the bran is lost. Heinzelmann is quoted as saying that 20 per cent of the phosphoric acid originally present is dissolved during steeping, soft waters removing considerably more ash than hard waters. That a large proportion of this loss occurs during steeping admits of no doubt, as can be readily proven by merely soaking whole barley in water for several hours and then testing the solution for potash, phosphoric acid, etc.

From the fact that such losses in mineral constituents occur during steeping and considering also some results obtained in this laboratory on the amount of salts removed from the straw and grain of

[a] Loc. cit. [b] Through Pure Products, 1906, 2: 330.

barley on soaking, it seems quite safe to assume that the results on the loss of these materials obtained by Wilfarth, Römer, and Wimmer[a] were not caused, as they conclude, by the excretion of plant food from the roots of plants, but by the action of rainfall, which may wash off the plant food that has exuded on the surface of the plant.

The loss on germination is of great importance from an economic view point. The extent of this loss, which is due to the growth of the germ, to respiration, and to the fact that some of the constituents of the barley are dissolved during the process of steeping, varies considerably in the various barleys. However, the variation in loss in barleys of the same variety is greater than the difference in loss between barleys of different varieties. This is due chiefly to the different methods of malting employed. The loss on germination as estimated from the 1,000-grain weight in the 30 samples of 6-row barley was over 20 per cent in some cases, especially in the sample from New York, 2 samples from Minnesota, and 1 from Wisconsin. On an average, however, the 6-row Manchurian or Oderbrucker barleys experienced a smaller loss during malting than those just cited, as did likewise the 6-row Bay Brewing barley and the 2-row barleys, as may be seen from the following table:

Comparison of the loss on malting different kinds of barley.

Number of samples.	Kind of barley.	Loss on malting.
		Per cent.
8	2-row	12.7
5	6-row Bay Brewing	13.0
30	6-row Manchurian	11.4

These results agree quite well with those of Kunz,[a] who found from 9 to 13 per cent to be the average loss during malting. Among the samples of 6-row barleys which were malted it is seen that on an average the loss of protein during this process has been greater in the high-protein than in the low-protein barleys; that is, 16 and 12 per cent, respectively.

CONCLUSIONS.

This study of the composition of American-grown barleys and malts has been made in an attempt to show the relative value for alcohol production and for brewing of the ordinary 6-row and 2-row varieties produced in different portions of the United States. The determination and comparison of the composition of these barleys and the corresponding malts have afforded an opportunity to study chemically and physically the changes taking place during the malting of the barley. The tabulated data give these comparative

[a] Loc. cit.

results in detail as well as the changes in composition. According to these figures the 2-row barleys are somewhat richer in starch, extract, bran, and endosperm, have a higher bushel and 1,000-grain weight, and a higher coefficient of mealiness and degree of dissolution than the 6-row varieties. On the other hand, the 2-row variety contains less protein, fiber, pentosans, hulls, sulphur, embryo, and steely grains than the 6-row. The Bay Brewing barleys have a higher bushel and 1,000-grain weight than the ordinary 6-row barley, but less protein. The Utah Winter barleys have the most endosperm and contain the most starch, yield the most extract, have the highest coefficient of mealiness and degree of dissolution, and contain the least protein.

The 6-row barley malts contain the highest percentage of protein, lecithin, soluble protein, and embryo, but are lowest in starch, extract (in coarse grist), bran, weight per bushel, and weight per 1,000 grains.

The 2-row barley malts are highest in weight per bushel, extract, and coefficient of mealiness, but lowest in fiber, pentosans, hulls, and embryo.

The Bay Brewing and Utah Winter barley malts are highest in starch, hulls, and weight per 1,000 grains, and lowest in protein, soluble protein, endosperm, extract (fine grist), and coefficient of mealiness.

It has been shown that large kernels yield a higher percentage of extract than small kernels of the same protein content. The former contain more starch, weigh more per bushel, and give a higher coefficient of mealiness. The heavier kernels average less in protein content and contain more starch. The small grains of the same variety contain more bran, hulls, fiber, pentosans, and ash than do the larger grains. When barleys are divided into two groups—those of high and low protein content—the former are richer in fiber, pentosans, hulls, bran, and embryo; the latter weigh more per bushel and per 1,000 grains, and have more mealy grains after steeping, besides containing more extract, starch, and soluble protein.

Mealy grains are generally lower in protein content. The permanently steely grains are richer in protein. A high phosphoric acid content is generally accompanied by high starch and low protein. A larger proportion of the protein of low-protein barley is soluble than of the high-protein barley. The average percentage of protein in 6-row barley is about 12; of 2-row barley, 11.5; of Bay Brewing barley, less than 11, and of Utah Winter barley, less than 10 per cent.

The most interesting changes occurring during the process of malting are the increase in sugars, lecithin, soluble protein, and embryo, and the decrease in starch, ash, phosphoric acid, potash, magnesia, lime, bran, hulls, endosperm, fiber, fat, and total protein. The pentosans undergo very little, if any, change.

TABLE I.—*Average analyses of ordinary 6-row barleys from different States.*

A. RESULTS OBTAINED BY BUREAU OF CHEMISTRY.

Number of samples.	State.	Water.	In water-free substance.																					
			Fat.	Fiber.	Pentosans.	Starch.	Ash.	Total phosphoric acid.	Total sulphur.	Lecithans as lecithin.	Total protein (N × 6.25).	Soluble protein.		Noncoagulable protein.		Soluble coagulable protein.		Hulls.	Bran.	Embryo.	Endosperm.	Weight per 1,000 grains.	Potash.	Lime.	Magnesia.
												In barley.	In total protein.	In barley.	In total protein.	In barley.	In total protein.								
		P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*Gms.*	*P. ct.*	*P. ct.*	*P. ct.*
3	Canada	8.62	1.95	5.65	9.66	59.22	3.03	1.09	0.193	0.50	11.83	1.96	16.59	1.32	11.13	0.65	5.46	11.89	11.45	2.46	73.39	27.51	0.73	0.09	0.19
1	Colorado	9.00	2.07	5.69	10.03	56.77	2.79	1.41	.159	.52	12.50	1.96	15.68	1.41	11.28	.55	4.40	12.29	13.36	2.25	71.90	29.33	.69	.07	.30
1	New York	8.66	1.99	5.31	9.28	56.38	2.75	1.00	.231	.58	14.19	2.43	17.12	1.57	11.06	.86	6.06	10.17	11.43	2.65	74.18	28.19	.72	.10	.19
5	South Dakota	8.38	1.93	6.13	10.76	59.02	2.95	.90	.182	.56	12.80	2.23	17.45	1.66	13.00	.57	4.46	13.68	11.90	2.62	71.07	25.47	.67	.06	.21
7	Iowa	8.26	2.01	6.10	10.53	58.44	3.02	.99	.180	.49	11.59	2.20	19.03	1.60	13.83	.60	5.21	13.09	11.67	2.70	71.72	25.70	.67	.08	.21
1	Illinois	9.65	2.06	5.82	9.31	58.57	2.76	1.16	.160	.43	11.44	2.11	18.44	1.49	13.02	.62	5.42	12.41	13.85	2.60	73.50	28.55	.72	.06	.21
1	Indiana	9.08	2.00	6.38	9.50	58.97	3.09	.98	.187	.60	11.94	2.15	18.00	1.59	13.32	.56	4.68	12.46	11.53	2.40	70.70	25.72	.76	.07	.30
6	Michigan	8.34	2.03	5.52	9.39	59.16	2.93	1.02	.181	.57	11.51	2.03	17.67	1.40	12.20	.63	5.46	12.28	11.39	2.55	71.94	26.77	.70	.09	.22
1	Kansas	8.97	1.85	6.46	8.79	62.25	2.97	.98	.198	.52	13.44	1.76	13.10	1.38	10.27	.38	2.83	13.76	11.75	2.38	72.81	27.76	.71	.07	.29
20	Minnesota	8.77	2.02	5.91	9.73	58.09	2.99	1.07	.180	.52	11.90	2.16	18.17	1.50	12.63	.66	5.54	12.81	11.91	2.54	72.10	27.66	.71	.07	.21
3	Montana	8.80	2.20	5.72	9.58	60.09	3.37	1.15	.201	.69	12.63	2.22	17.66	1.58	12.56	.64	5.10	12.71	11.45	2.44	69.93	24.76	.76	.09	.26
1	Ohio	8.75	1.92	5.63	8.31	57.01	2.78	1.17	.179	.41	11.69	2.27	19.42	1.41	12.06	.86	7.36	14.04	11.36	2.64	71.20	27.60	.65	.07	.21
34	Wisconsin	8.83	2.01	5.58	9.38	59.20	2.95	1.08	.180	.51	11.64	2.04	17.49	1.40	12.06	.68	5.43	12.30	11.53	2.56	73.83	28.54	.71	.08	.22
84	Average	8.71	2.02	5.76	9.64	58.87	2.98	1.06	.182	.52	11.86	2.22	17.73	1.46	12.38	.65	5.35	12.06	11.69	2.44	72.69	26.92	.70	.08	.22

Number of samples.	State.	Weight.			In water-free substance.					Water.	Character of endosperm.						Degree of dissolution.	Germ energy.	Germ capacity.	Protein soluble in water.	Water-soluble protein coagulated.	Coefficient of mealiness (Brown).		
											Before steeping.			After steeping.								Before steeping.	After steeping.	Difference or increase in mellowness.
		Per hectoliter.	Per bushel.	Protein (N × 6.25).	Extract.	Weight per 1,000 grains.	Weight per 1,000 grains.	Water-soluble protein.	Coagulable water-soluble protein.		Steely.	Half steely.	Mealy.	Steely.	Half steely.	Mealy.								
		Kilos.	*Pounds.*	*P. ct.*	*P. ct.*	*Grams.*	*Ounces.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*		*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*			
3	Canada	61.6	47.75	12.02	71.66	26.88	0.95	1.95	0.55	11.42	59	30	11	16	19	65	68.5	90.8	96.1	16.2	28.3	26.59	74.66	48.07
1	Colorado	64.8	50.25	11.68	72.13	28.77	1.01	1.84	.58	10.63	27	59	14	5	24	71	80.3	90.1	99.9	15.7	31.5	43.77	83.05	39.28
1	New York	61.3	47.50	14.31	70.94	27.91	.98	2.16	.65	9.91	53	36	11	13	28	59	64.9	92.9	99.8	15.1	30.1	29.53	73.13	43.60
5	South Dakota	59.1	46.00	13.09	69.32	24.03	.85	2.12	.51	12.62	34	49	17	10	22	68	76.2	89.5	97.8	16.6	24.4	41.84	79.10	37.26
7	Iowa	60.9	47.25	11.77	70.55	24.77	.87	2.01	.53	12.03	38	41	21	6	18	76	88.9	88.0	98.2	17.0	26.3	40.88	85.06	44.18
1	Illinois	65.4	50.75	12.00	71.96	28.18	.99	1.77	.59	10.04	72	24	4	1	20	79	82.1	98.3	100.0	14.8	33.3	16.72	89.01	72.29
1	Indiana	60.3	46.75	12.06	70.87	24.33	.86	2.11	.66	10.39	70	25	5	6	28	66	69.2	91.8	99.8	17.5	31.2	18.20	80.06	61.86
6	Michigan	60.7	47.00	11.53	71.30	26.06	.92	1.92	.54	9.93	64	31	5	5	22	73	76.2	92.1	98.9	16.6	28.3	21.64	84.05	62.41
1	Kansas	58.7	45.50	12.50	69.57	27.76	.98	1.88	.57	10.53	87	10	3	15	38	47	48.4	91.9	99.0	15.0	30.3	8.87	66.15	57.28
20	Minnesota	60.4	46.75	12.17	70.83	26.28	.92	2.04	.59	11.88	46	41	13	7	23	70	77.6	92.1	97.6	16.7	28.6	33.96	81.57	47.61
3	Montana	59.0	45.75	12.60	68.79	23.75	.79	2.10	.94	9.49	42	44	14	8	31	61	67.9	93.7	98.9	16.8	32.4	36.42	76.58	40.16
1	Ohio	64.8	50.25	11.93	71.06	26.25	.93	1.90	.56	12.76	40	45	15	2	20	78	89.1	93.3	96.7	15.9	29.5	37.90	88.02	50.12
34	Wisconsin	59.5	46.25	11.76	71.66	27.82	.98	1.95	.61	12.04	37	44	19	7	21	72	83.5	94.2	98.7	16.6	30.8	41.37	82.57	41.20
84	Average	60.7	46.70	12.00	71.09	26.63	.93	1.99	.60	11.67	43	41	16	7	22	71	79.7	92.5	98.3	16.6	29.3	36.37	81.79	45.37

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TABLE II.—*Average results of barley analyses—Two-row, Bay Brewing, and Utah Winter.*

A. RESULTS OBTAINED BY BUREAU OF CHEMISTRY.

Number of samples.	State.	Water.	In water-free substance.																					
			Fat.	Fiber.	Pentosans.	Starch.	Ash.	Phosphoric acid.	Sulphur.	Lecithans as lecithin.	Protein (N×6.25).	Soluble protein.		Noncoagulable soluble protein.		Coagulable soluble protein.		Hulls.	Bran.	Embryo.	Endosperm.	Weight per 1,000 grains.	Potash.	Lime.	Magnesia.
												In barley.	In total protein.	In barley.	In total protein.	In barley.	In total protein.								
	BAY BREWING.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*Gms.*	*P. ct.*	*P. ct.*	*P. ct.*
8	California	8.23	2.06	6.72	9.84	58.23	3.03	1.00	0.143	0.54	9.77	1.52	15.51	1.44	11.70	0.37	3.81	14.46	11.37	2.44	69.91	35.82	0.75	0.07	0.24
1	Oklahoma	9.14	2.19	8.12	10.83	58.14	2.95	.81	.206	.69	15.44	2.35	15.22	1.64	10.62	.71	4.60	15.87	10.73	2.76	70.66	28.04	.69	.09	.21
3	Idaho	7.70	2.06	6.36	9.72	57.82	2.96	1.08	.152	.57	10.42	1.64	15.82	1.18	11.31	.47	4.51	14.48	10.75	2.34	70.05	41.20	.56	.07	.24
1	Kansas	10.32	2.02	7.31	10.48	59.66	3.41	1.06	.188	.47	13.69	2.19	16.00	1.52	11.10	.67	4.90	15.00	10.79	2.99	71.00	30.56	.83	.10	.21
3	Washington	8.35	2.01	6.25	9.48	58.33	3.12	1.08	.146	.56	10.06	1.66	16.44	1.21	12.00	.45	4.46	13.91	10.86	2.37	69.01	40.76	.69	.07	.26
2	Tennessee	8.78	1.84	5.70	9.58	58.82	2.40	.84	.168	.49	12.26	1.78	14.58	1.26	10.30	.52	4.06	13.56	11.09	2.25	72.62	29.90	.68	.08	.20
18	Average	8.39	2.03	6.58	9.82	58.32	2.98	1.00	.154	.55	10.73	1.67	15.62	1.35	11.44	.45	4.19	14.38	11.08	2.44	70.20	36.16	.70	.07	.23
	UTAH WINTER (6-ROW).																								
2	Idaho	8.74	2.19	5.88	9.72	59.97	2.90	.95	.182	.53	9.53	1.63	17.18	1.18	12.45	.45	4.73	13.15	10.89	2.00	72.74	37.98	.61	.09	.20
5	Utah	8.48	1.81	5.55	8.89	59.95	2.90	.93	.170	.55	10.55	1.99	18.90	1.48	14.06	.51	4.84	12.88	10.60	1.98	71.69	37.36	.68	.08	.21
1	Washington	8.20	2.00	5.25	8.41	58.68	2.72	.92	.123	.49	7.75	1.33	17.16	1.25	16.13	.08	1.03	12.10	11.78	1.84	73.49	38.93	.57	.10	.22
1	Montana	8.06	2.41	7.40	8.39	60.37	2.73	.87	.176	.49	10.06	1.96	19.48	1.49	14.81	.47	4.67	13.24	11.31	1.82	72.20	37.40	.54	.09	.20
9	Average	8.46	1.98	5.79	8.96	59.86	2.87	.93	.168	.53	9.96	1.83	18.39	1.39	14.02	.44	4.37	12.89	10.87	1.95	72.80	37.67	.64	.09	.21
	TWO-ROW.																								
2	California	8.82	2.15	5.52	8.66	60.38	2.72	.90	.161	.49	10.66	1.55	14.76	1.12	10.64	.43	4.12	11.08	12.71	2.62	72.02	35.28	.78	.07	.20
1	Canada	9.31	2.27	4.79	8.33	62.54	2.78	.99	.154	.33	10.44	1.96	18.77	1.33	12.74	.63	6.03	10.70	10.56	2.50	75.63	38.29	.75	.07	.23
1	Germany	9.36	2.04	5.56	8.33	64.72	2.52	1.03	.180	.57	9.13	1.64	17.96	1.26	13.80	38	4.16	10.07	11.56	2.13	73.01	48.05	.74	.07	.18
5	Colorado	8.96	2.00	5.63	8.62	58.59	2.92	1.13	.169	.53	13.10	2.32	17.70	1.98	12.82	.63	4.89	9.79	12.22	2.50	72.33	41.33	.70	.08	.25
1	New York	8.77	1.83	4.38	8.00	60.22	2.99	1.10	.183	.55	13.06	2.27	17.38	1.61	12.33	.66	5.05	9.28	10.20	2.56	77.64	32.73	.79	.11	.21
1	South Dakota	8.58	1.75	6.13	9.40	60.03	2.99	.86	.182	.42	12.06	2.04	16.92	1.33	11.03	.71	5.89	12.37	13.39	2.59	71.04	28.35	.73	.04	.25
1	Idaho	9.02	2.00	4.70	8.42	61.21	3.06	1.02	.160	.58	10.69	1.72	16.09	1.21	11.32	.51	4.77	10.95	14.49	2.66	69.28	36.81	.75	.06	.24

1	Kansas	10.00	2.23	5.38	8.44	55.91	3.13	1.27	.256	.59	17.69	2.74	15.49	1.67	9.44	1.07	6.05	11.70	11.35	2.93	73.62	35.07	.68	.09	.21
5	Montana	8.61	1.98	4.81	8.09	59.78	2.85	1.05	.165	.54	9.92	1.97	19.91	1.38	13.96	.59	5.95	10.18	12.71	2.41	72.13	38.77	.68	.08	.22
18	Average	8.92	2.01	5.23	8.41	59.08	2.88	1.05	.173	.52	11.64	2.05	17.78	1.53	12.55	.61	5.24	10.39	12.31	2.51	72.58	38.35	.72	.08	.22
	HULL-LESS (2-ROW).																								
1	Montana	8.73	2.17	5.62	8.38	65.47	2.24	1.03	.159	.57	12.06	2.27	18.82	1.76	14.59	.51	4.23	.....	18.23	2.90	79.39	30.48	.66	.07	.19

TABLE II.—*Average results of barley analyses—Two-row, Bay Brewing, and Utah Winter*—Continued.

B. RESULTS OBTAINED BY ROBERT WAHL.

Number of samples.	State.	Weight.		In water-free substance.						Character of endosperm.						Degree of dissolution.	Germ energy.	Germ capacity.	Water-soluble protein.	Water-soluble protein coagulated.	Coefficient of mealiness (Brown).		
										Before steeping.			After steeping.										
		Per hectoliter.	Per bushel.	Protein (N×6.25).	Extract.	Weight per 1,000 grains.	Weight per 1,000 grains.	Water-soluble protein.	Coagulable water-soluble protein.	Water.	Steely.	Half steely.	Mealy.	Steely.	Half steely.	Mealy.						Before steeping.	After steeping.	Difference or increase in mellowness.
	BAY BREWING (6-ROW).	*Kilos.*	*Pounds.*	*P. ct.*	*P. ct.*	*Grams.*	*Ounces.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*			*P. ct.*	*P. ct.*	*P. ct.*			
8	California	58.1	45.00	10.13	71.05	35.29	1.24	1.49	0.41	10.49	68	26	6	5	14	81	85.3	93.5	99.5	14.9	27.2	20.18	87.43	67.38
1	Oklahoma	50.6	39.25	15.75	62.93	28.04	.99	3.20	1.08	11.44	35	41	24	8	45	47	54.3	91.5	95.0	20.3	33.7	44.85	69.58	24.73
3	Idaho	60.3	46.75	10.06	72.23	40.00	1.41	1.63	.49	8.91	78	20	2	0	6	94	96.2	90.9	99.8	16.3	29.9	13.28	96.83	83.56
1	Kansas	51.6	40.00	13.56	68.44	29.74	1.05	2.02	.52	12.03	52	31	17	7	24	69	79.6	69.4	84.0	14.9	25.8	33.02	81.07	48.05
3	Washington	61.0	47.25	9.95	72.27	40.80	1.44	1.63	.49	10.85	76	20	4	0	5	95	97.6	95.3	99.7	16.2	29.4	14.76	95.84	81.08
2	Tennessee	59.0	45.75	12.21	71.43	28.50	1.00	1.90	.59	12.36	48	43	9	19	30	51	55.4	98.1	99.8	15.5	31.3	30.98	86.69	55.71
18	Average	58.0	45.10	10.82	70.89	35.53	1.25	1.70	.50	10.63	66	27	7	5	16	79	83.8	92.4	98.5	15.6	28.8	21.41	87.63	67.57
	UTAH WINTER (6-ROW).																							
2	Idaho	57.7	44.75	9.34	73.89	37.44	1.31	1.70	.55	9.63	57	17	26	2	16	82	102.9	91.5	99.2	18.2	32.2	34.82	90.51	55.70
5	Utah	62.3	48.25	10.41	74.21	36.41	1.28	2.12	.56	10.24	77	19	4	3	12	85	87.8	91.7	98.8	20.4	26.3	14.27	91.03	76.76
1	Washington	60.3	46.75	7.59	75.04	37.73	1.33	1.39	.42	9.67	76	20	4	0	3	97	100.8	93.4	99.9	18.5	30.2	14.76	98.50	83.74
1	Montana	64.1	49.75	10.31	74.33	37.40	1.32	1.96	.57	10.21	52	29	19	6	10	84	99.2	97.5	99.9	19.0	29.1	34.02	89.06	55.04
9	Average	61.3	47.50	9.84	74.24	36.89	1.29	1.93	.54	10.04	69	20	11	3	12	85	93.8	92.5	99.1	19.5	28.4	21.08	91.54	70.44
	2-ROW.																							
2	California	65.9	51.25	11.09	73.94	35.28	1.24	1.66	.52	11.17	56	33	11	4	17	79	89.5	95.4	99.9	15.0	30.6	28.06	87.54	59.48
1	Canada	65.1	50.50	10.75	74.18	38.08	1.34	1.98	.62	12.18	91	6	3	1	24	75	77.2	92.0	95.2	18.4	31.3	6.91	87.01	80.11
1	Germany	71.9	55.75	9.59	79.11	47.62	1.68	1.45	.44	15.38	64	31	5	0	4	96	100.8	90.7	92.5	15.2	30.3	21.14	98.00	76.86
5	Colorado	66.1	51.00	13.17	71.48	41.65	1.47	2.09	.69	10.35	77	19	4	16	37	47	48.7	95.8	99.2	15.8	32.8	18.69	68.64	49.95
1	New York	64.8	51.25	12.62	72.73	31.35	1.15	2.14	.68	9.91	53	37	10	4	25	71	77.8	90.2	95.0	16.5	31.8	29.03	83.54	54.51
1	South Dakota	62.6	48.50	11.62	69.44	28.35	1.00	2.06	.55	10.64	80	20	0	14	36	50	50.0	90.5	99.7	17.7	21.8	10.80	68.14	57.34
1	Idaho	67.7	52.25	11.00	73.67	37.48	1.3	1.70	.54	10.54	79	21	0	3	12	85	85.0	96.6	98.4	15.4	31.8	11.29	91.03	79.74

1	Kansas	60.9	47.25	17.44	69.39	34.70	1.22	2.69	.94	11.56	26	52	22	7	28	65	77.1	82.9	93.8	15.4	34.9	48.26	79.07	30.81
5	Montana	71.1	55.00	10.03	76.45	38.85	1.37	1.91	.61	10.70	47	30	23	0	4	96	116.4	96.1	99.3	19.0	32.3	38.17	98.00	59.83
18	Average	67.2	52.00	11.73	73.67	38.31	1.36	1.96	.63	11.00	62	27	11	6	21	73	81.8	94.1	95.4	17.3	31.6	25.43	83.61	58.18
	HULL-LESS (2-ROW).																							
1	Montana	79.3	63.50	12.87	76.05	29.10	1.03	1.67	.45	9.85	46	24	30	0	1	99	128.6	97.8	98.3	12.9	27.0	42.46	99.50	57.04

TABLE III.—*Analyses of malts, arranged by States.*

A. RESULTS OBTAINED BY BUREAU OF CHEMISTRY.

Number of samples.	State.	Water.	In water-free substance.																		
			Fat.	Fiber.	Pentosans.	Starch.	Invert sugar.	Cane sugar.	Ash.	Total phosphoric acid.	Potassium oxid.	Calcium oxid.	Magnesium oxid.	Total sulphur.	Lecithans as lecithin.	Total protein (N ×6.25).	Soluble protein.		Soluble noncoagulable protein.		Soluble coagulable protein.	
																	In malt.	In total protein.	In malt.	In total protein.	In malt.	In total protein.
	ORDINARY 6-ROW MALTS.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
1	South Dakota	6.11	2.07	6.16	10.73	50.86	8.61	3.80	2.47	0.91	0.33	0.08	0.18	0.234	0.65	13.37	4.71	35.23	3.83	28.65	0.88	6.58
1	Illinois	5.11	2.04	6.68	11.47	45.93	.....	.....	2.55	.84	.....	.....	.....	.258	.78	11.38	4.63	40.69	3.67	32.25	.96	8.44
1	Iowa	4.29	1.91	6.11	10.69	43.69	6.94	5.16	2.46	.87	.....	.....	.....	.211	.75	13.19	4.75	36.01	3.75	28.43	1.00	7.58
3	Michigan	5.97	2.11	5.84	10.61	47.79	7.81	4.55	2.81	1.10	.42	.....	.21	.210	.76	11.27	3.96	35.31	3.17	28.28	.78	7.03
8	Minnesota	5.89	2.17	5.88	10.60	48.30	6.62	4.80	2.70	1.05	.38	.07	.21	.210	.78	11.60	4.16	35.89	3.32	28.63	.84	7.26
1	Ohio	5.87	2.18	6.43	11.86	47.49	.....	.....	3.10	1.10	.32	.08	.20	.172	.74	11.49	4.23	36.18	3.67	31.40	.56	4.78
14	Wisconsin	5.92	2.13	5.99	10.34	46.15	8.31	4.59	2.67	1.07	.40	.....	.21	.224	.78	11.30	4.34	38.39	3.47	30.69	.87	7.70
1	Colorado	6.62	2.37	5.73	10.72	50.92	.....	.....	2.80	.97	.34	.07	.20	.181	.67	11.44	3.43	29.98	2.95	25.79	.48	4.20
	Minimum	3.71	1.91	5.19	9.20	41.22	3.76	3.43	2.46	.84	.32	.07	.19	.163	.65	10.13	3.43	29.13	2.50	21.17	.48	4.20
	Maximum	7.67	2.39	7.24	11.88	51.67	11.02	5.81	3.10	1.17	.49	.09	.25	.258	.90	13.37	6.23	46.60	5.27	42.36	1.06	9.44
30	Average	5.86	2.14	5.98	10.56	48.39	.....	.....	2.69	1.05	.39	.....	.21	.218	.77	11.52	4.25	38.17	3.42	29.33	.84	7.29
	BAY BREWING AND UTAH WINTER MALTS (6 ROW).																					
2	California	5.42	2.14	6.61	10.59	47.01	7.26	5.44	2.36	.97	.40	.07	.24	.153	.68	8.00	2.75	34.40	2.42	30.20	.34	4.21
2	Idaho	7.50	2.14	6.04	10.50	52.22	6.88	3.72	2.61	1.00	.43	.07	.22	.144	.71	10.24	3.10	30.25	2.51	24.50	.59	5.75
1	Utah	6.08	2.12	5.66	10.46	50.70	7.33	3.76	2.57	.94	.47	.06	.19	.159	.67	10.25	3.28	32.00	2.79	27.22	.49	4.78
2	Washington	6.02	2.04	5.80	10.70	50.30	5.70	5.10	2.68	1.02	.41	.06	.21	.180	.72	10.34	3.10	30.25	2.61	25.80	.48	4.45
1	Montana	5.11	2.17	5.31	9.76	51.69	.....	.....	2.11	.69	.42	.06	.18	.196	.67	9.37	3.28	35.00	2.76	29.45	.52	5.55
	Minimum	4.81	1.90	5.22	9.72	46.73	5.59	2.35	2.11	.69	.34	.05	.19	.140	.66	7.81	2.71	29.55	2.39	24.50	.27	3.30
	Maximum	9.51	2.21	6.86	11.68	53.45	7.77	5.57	2.82	1.14	.48	.08	.28	.202	.78	12.44	3.56	35.72	2.86	30.60	.70	6.75
8	Average	6.12	2.11	5.99	10.47	51.43	.....	.....	2.50	.94	.41	.07	.22	.165	.69	9.58	3.05	32.09	2.62	27.21	.47	4.90

	2-ROW MALTS.																				
4	Montana	4.94	1.96	4.55	8.88	51.48	6.46	4.90	2.42	1.0	.40	.07	.20	.174	.68	9.47	3.33	35.18	2.71	28.70	.61	6.46
1	New York	6.33	2.03	4.94	9.93	48.94	11.04	3.96	2.96	1.16	.48	.06	.20	.230	.77	13.25	5.47	41.29	4.55	34.34	.92	6.95
	Minimum	4.27	1.76	4.27	8.32	48.94	5.75	3.96	2.23	.98	.34	.06	.17	.142	.67	8.56	3.09	34.19	2.51	27.33	.55	5.75
	Maximum	6.33	2.16	4.94	9.93	52.50	11.04	5.63	2.96	1.16	.48	.08	.22	.230	.77	13.25	5.47	41.29	4.55	34.34	.92	6.95
5	Average	5.20	1.97	4.62	9.08	50.96	7.37	4.71	2.52	1.06	.41	.07	.20	.185	.70	10.22	3.75	36.40	3.08	29.82	.67	6.55

TABLE III.—*Analyses of malts, arranged by States*—Continued.

A. RESULTS OBTAINED BY BUREAU OF CHEMISTRY—Continued.

Number of samples.	State.	In water-free substance.																Malt.	Barley.	Ratio of the weight per 1,000 of malt to barley.
		Hulls.	Bran.	Embryo.	Endosperm.	Total protein.		Soluble protein.		Soluble noncoagulable protein.		Soluble coagulable protein.		Soluble protein in total protein.		Soluble noncoagulable protein in total protein.		Soluble coagulable protein in total protein.				
						In barley.	In malt calculated to original barley.	In barley.	In malt calculated to original barley.	In barley.	In malt calculated to original barley.	In barley.	In malt calculated to original barley.	In barley.	In malt calculated to original barley.	In barley.	In malt calculated to original barley.	In barley.	In malt calculated to original barley.	Weight per 1,000 grains.	Weight per 1,000 grains.	
	ORDINARY 6-ROW MALTS.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*Grams.*	*Grams.*	
1	South Dakota	14.12	8.46	5.52	71.91	13.69	11.03	2.20	3.89	1.62	3.16	0.58	0.73	16.07	35.27	11.83	28.65	4.24	6.62	21.69	26.28	82.53
1	Illinois	14.04	7.63	6.15	72.18	11.44	10.12	2.11	4.12	1.49	3.26	.62	.85	18.44	40.71	13.02	32.21	5.42	8.39	25.39	28.55	88.93
1	Iowa	14.05	8.34	5.80	71.32	13.06	11.35	2.35	4.09	1.64	3.23	.71	.86	17.99	36.64	12.56	28.46	5.43	7.58	22.92	26.64	86.04
3	Michigan	13.17	8.15	4.48	74.20	11.63	10.13	2.05	3.54	1.37	2.85	.68	.70	17.64	35.31	11.79	28.28	5.85	7.02	24.97	26.31	94.78
8	Minnesota	12.89	8.00	4.95	74.16	11.63	10.57	2.08	3.33	1.42	2.95	.66	.74	17.85	35.90	12.19	28.63	5.66	7.26	24.90	28.40	84.47
1	Ohio	14.75	7.29	4.81	73.16	11.69	9.98	2.27	3.68	1.41	3.19	.86	.49	19.42	36.87	12.06	31.96	7.36	4.91	23.98	27.60	86.88
14	Wisconsin	13.23	8.20	5.56	73.01	11.63	9.95	2.09	3.75	1.41	3.01	.68	.75	17.76	38.46	12.12	30.76	5.83	7.69	25.14	28.51	88.48
1	Colorado	11.83	8.05	4.08	76.04	12.50	10.19	1.96	3.06	1.41	2.63	.55	.43	15.68	30.00	11.28	25.75	4.40	4.25	28.63	29.33	79.61
	Minimum	11.83	7.04	3.80	76.04	10.25	8.02	1.83	2.81	1.25	2.24	.46	.43	15.50	29.15	10.64	21.20	3.90	4.25	21.69	24.49	73.28
	Maximum	14.70	9.77	7.16	75.75	13.69	11.81	2.51	5.34	1.73	4.52	.88	.94	20.49	46.60	13.98	39.45	7.36	9.46	28.63	35.75	98.47
30	Average	13.21	8.10	5.34	73.21	11.77	10.22	2.10	3.62	1.43	2.99	.68	.72	17.73	37.06	12.11	29.74	5.71	7.29	25.02	28.14	87.98
	BAY BREWING AND UTAH WINTER MALTS (6 ROW).																					
2	California	15.68	8.61	5.20	70.51	10.19	8.16	1.72	2.78	1.32	2.46	.41	.33	16.90	34.37	12.88	30.15	4.01	4.22	33.14	33.42	84.71
2	Idaho	15.71	8.54	4.34	71.42	9.69	8.79	1.56	2.66	1.12	2.16	.43	.50	16.69	30.26	11.65	25.42	4.44	5.76	32.40	37.74	85.81
1	Utah	11.22	8.77	3.63	76.39	10.69	9.13	2.11	2.92	1.57	2.48	.54	.44	19.74	31.98	14.69	27.16	5.05	4.82	33.58	37.71	89.05
2	Washington	13.54	8.94	5.23	72.29	9.12	9.12	1.60	2.72	1.27	2.30	.34	.42	17.49	30.22	14.18	25.79	3.31	4.44	35.34	40.08	88.17
1	Montana	12.57	9.87	4.25	73.31	10.06	8.10	1.90	2.83	1.49	2.38	.47	.45	19.48	35.00	14.81	29.45	4.67	5.55	32.33	37.40	86.44

	Minimum	11.22	8.26	3.63	69.97	7.75	6.62	1.33	2.33	1.06	2.02	.08	.24	15.78	28.57	11.23	22.99	1.03	3.28	30.73	28.57	84.08
	Maximum	16.57	9.87	5.94	76.39	11.44	10.92	2.11	3.35	1.57	2.89	.59	.61	19.74	35.65	16.13	30.51	5.59	6.77	36.18	41.23	99.05
8	Average	14.20	8.74	4.70	72.27	9.85	8.79	1.73	2.81	1.31	2.38	.42	.43	17.53	32.08	13.36	27.19	4.15	4.90	33.45	37.19	89.70
	2-ROW MALTS.																					
4	Montana	10.28	8.82	4.10	76.80	9.85	8.26	1.94	2.89	1.34	2.37	.59	.54	19.59	35.19	13.64	28.72	5.99	6.46	33.68	38.69	87.13
1	New York	11.97	7.60	4.87	75.57	13.06	10.54	2.27	4.35	1.61	3.62	.66	.73	17.38	41.27	12.33	34.35	5.05	6.93	26.03	32.73	79.53
	Minimum	9.46	7.60	3.65	75.39	9.50	7.60	1.80	2.74	1.21	2.22	.51	.47	17.38	34.17	12.33	27.36	5.05	5.78	26.03	32.73	79.53
	Maximum	12.57	10.26	4.87	78.67	13.06	10.54	2.27	4.35	1.61	3.62	.67	.73	20.40	41.27	15.30	34.35	6.83	6.93	34.03	39.63	90.81
5	Average	10.61	8.57	4.25	76.55	10.48	8.70	2.00	3.18	1.39	2.62	.59	.57	19.14	36.40	13.36	29.84	5.80	6.55	32.14	37.49	85.60

TABLE III.—*Analyses of malts, arranged by States*—Continued.

B. RESULTS OBTAINED BY ROBERT WAHL.

Number of samples.	State.	Protein (N × 6.25).	Nitrogen.	Extract, fine grist.	Weight.		Protein dissolved by mashing.	Coagulable protein dissolved by mashing.	Moisture.	Steely.	Half steely.	Mealy.	Growth of acrospire.					Extract, coarse grist.	Difference in extract.	Weight.		Total protein dissolved by mashing.	Soluble protein coagulated.	Run of wort.	Coefficient of mealiness (Brown).
					Per 1,000 grains.	Per 1,000 grains.							0 to 0.25.	0.25 to 0.5.	0.5 to 0.75.	0.75 to 1.	Overgrown.			Per hectoliter.	Per bushel.				
	ORDINARY 6-ROW MALTS.	*P. ct.*	*P. ct.*	*P. ct.*	*Gms.*	*Oz.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*			*Kilos.*	*Lbs.*	*P. ct.*	*P. ct.*		
1	South Dakota	13.31	2.13	71.71	21.00	0.74	5.08	0.189	6.42	11	18	71	1	0	14	85	0	68.85	2.86	46.7	36.25	38.0	3.7	2.1	80.11
1	Illinois	12.12	1.94	72.61	24.93	.88	4.47	.215	5.39	1	4	95	1	0	7	92	0	71.53	1.08	45.4	35.25	36.8	4.8	1.9	97.01
1	Iowa	13.00	2.08	72.08	22.67	.80	4.89	.155	8.51	17	7	76	2	2	18	78	0	67.53	4.55	45.8	35.50	37.6	3.2	2.0	79.67
3	Michigan	11.64	1.86	73.99	24.41	.86	4.16	.161	6.81	3	11	86	5	2	27	66	0	71.13	2.68	48.5	37.50	35.8	3.8	2.9	91.53
9	Minnesota	11.75	1.88	72.86	24.18	.85	4.37	.197	7.26	7	16	77	3	3	13	80	1	68.50	4.36	42.5	33.0	37.1	4.5	2.0	85.07
1	Ohio	11.50	1.84	72.91	23.32	.82	4.75	.161	7.45	9	13	78	2	3	26	68	1	68.58	4.33	.....	.....	41.3	3.4	2.5	84.59
14	Wisconsin	11.90	1.90	73.65	24.80	.87	4.39	.176	6.39	2	8	90	2	2	11	82	3	70.70	2.94	43.7	34.0	36.7	4.0	2.1	94.02
1	Colorado	11.56	1.85	73.18	28.32	1.00	3.40	.202	8.38	8	32	60	1	0	38	60	1	68.47	4.71	51.3	39.75	29.4	5.9	4.8	76.08
	Minimum	10.62	1.70	69.52	21.03	.74	3.40	.129	5.39	0	3	60	0	0	1	53	0	62.24	1.08	44.2	34.25	29.4	3.0	1.9	77.62
	Maximum	14.19	2.27	76.29	28.32	1.00	5.65	.372	11.75	17	32	97	7	10	42	94	10	74.08	9.54	52.2	40.50	46.0	8.8	4.9	98.50
31	Average	11.90	1.90	73.27	24.46	.85	4.39	.187	6.82	5	12	83	2	2	15	79	2	69.82	3.44	44.3	34.50	36.8	4.2	2.3	89.56
	BAY BREWING AND UTAH WINTER MALTS (6-ROW).																								
2	California	8.15	1.30	71.98	33.99	1.19	3.13	.141	6.44	4	6	90	2	3	28	67	0	70.22	1.76	45.4	35.25	38.3	3.6	2.6	93.94
2	Idaho	10.09	1.61	72.61	32.89	1.16	3.26	.107	6.36	0	9	91	3	2	30	65	0	69.56	3.05	46.3	35.75	32.3	3.2	1.7	95.50
1	Utah	10.87	1.74	73.90	32.85	1.16	3.51	.142	6.40	10	25	65	7	8	41	44	0	66.60	7.30	48.7	37.75	32.3	4.0	2.3	77.60
2	Washington	10.31	1.65	74.51	34.84	1.23	3.46	.123	6.77	3	16	81	1	4	36	59	0	72.60	1.91	49.3	38.25	33.9	3.5	.9	89.03
1	Montana	9.56	1.53	75.26	32.34	1.14	3.47	.136	4.62	3	11	86	3	4	8	74	11	72.84	2.42	45.4	35.25	36.3	3.9	2.1	91.53
	Minimum	8.12	1.30	70.68	31.61	1.11	3.10	.107	5.85	0	3	65	0	0	8	41	0	66.60	1.09	44.2	34.25	31.8	3.2	1.1	77.60
	Maximum	12.31	1.97	77.19	35.16	1.24	3.96	.202	7.32	10	27	97	7	8	51	89	11	75.67	7.30	50.0	38.75	38.8	4.0	4.8	98.50
8	Average	9.69	1.55	73.42	33.58	1.18	3.34	.128	6.28	4	12	84	3	4	29	63	1	70.52	2.89	46.6	37.0	34.6	3.6	1.8	90.53

	TWO-ROW MALTS.																								
4	Montana	9.63	1.54	78.68	33.48	1.18	3.61	.153	4.92	0	4	96	3	3	28	66	0	76.73	1.96	53.1	41.25	38.0	4.3	2.2	97.66
1	New York	13.81	2.21	72.93	25.69	.90	4.91	.219	4.69	13	27	60	2	0	21	77	0	68.37	4.56	48.7	37.75	35.6	4.5	1.6	73.63
	Minimum	8.18	1.31	72.93	25.69	.90	3.27	.117	4.10	0	3	60	1	0	13	58	0	68.37	1.69	48.7	37.75	33.3	3.4	1.1	73.63
	Maximum	13.81	2.21	79.74	33.84	1.19	4.91	.219	5.51	13	27	97	7	4	37	79	0	78.05	4.56	56.1	43.50	47.1	4.8	3.0	98.50
5	Average	10.32	1.65	77.52	31.92	1.12	3.87	.166	4.87	3	9	88	3	2	26	68	1	75.06	2.48	2.25	40.50	37.5	4.3	2.1	92.85

TABLE IV.—*Per cent of constituents altered by malting, averaged by States.*

Number of sample	State.	Fat.	Fiber.	Pentosans.	Starch.	Invert sugar.	Cane sugar.	Ash.	Total phosphoric acid.	Potassium oxid.	Calcium oxid.	Magnesium oxid.	Total sulphur.	Lecithans as lecithin.	Hulls.	Bran.	Embryo.	Endosperm.	Total protein.	Soluble protein.	Soluble noncoagulable protein.	Soluble coagulable protein.
90	California	−18.7	7.6	− 8.3	−32.2	323.9	93.4	−42.1	−19.6	−5.34	−41.1	2.7	−17.8	3.6	− 2.7	−37.6	66.1	−16.3	−26.0	58.4	77.2	− 2.9
116	Colorado	− 1.9	−10.3	− 4.7	−20.0	.....	.....	−10.7	−38.3	−56.5	−14.2	−40.0	1.9	15.3	[a]−14.3	−46.4	61.7	[a]− 5.8	−18.4	56.0	86.0	−22.0
102	South Dakota	−20.1	− 7.6	−10.4	−27.9	318.2	92.9	−23.6	− 6.2	−59.0	−30.0	−28.6	28.7	0.0	−19.8	−37.8	63.4	−16.6	−19.4	76.8	95.1	25.9
68	Idaho	−15.0	−36.7	−12.7	−21.6	486.2	−18.6	−26.5	−16.5	− 4.7	0.0	−29.7	− 9.1	11.3	−18.1	−25.8	55.0	− 9.0	− 6.1	75.8	107.5	− 2.3
67		−12.7	−11.5	− 4.9	−22.3	183.1	158.8	−22.9	−11.5	−47.7	−50.0	−14.3	−18.1	21.3	− 6.3	−33.6	88.6	−15.5	−12.3	65.6	75.8	37.2
114	Illinois	−12.1	2.1	9.7	−30.3	.....	184.5	−17.8	−35.3	.....	.....	.....	43.1	60.5	.6	−50.9	110.4	−12.6	−11.5	95.3	118.8	37.1
91	Iowa	−19.2	−11.5	− 2.7	−33.0	251.2	48.5	−28.1	−12.8	.....	.....	.....	7.1	8.3	−11.5	−36.7	84.1	−12.0	−13.1	74.0	97.0	21.1
46	Michigan	− 5.2	−10.5	−10.2	−28.8	466.0	61.1	−14.8	− 3.9	−52.3	.....	− 9.1	− 3.6	15.7	−10.0	−35.2	28.5	− 5.5	−16.4	70.0	97.0	19.4
53		2.1	− 2.4	− 6.7	−29.0	358.0	171.0	−18.5	− 3.8	−42.1	−27.3	−28.0	13.8	37.2	− 6.0	−37.5	53.8	[a]− 8.3	15.4	82.0	165.0	4.4
58		9.1	− 1.0	6.5	−35.0	510.0	129.0	−14.0	− 6.9	.....	.....	.....	20.0	25.0	− 7.5	−33.5	64.3	[a]− 6.7	− 9.0	62.0	100.0	−14.0
104	Minnesota	5.4	− 4.1	2.2	−25.6	.....	.....	−19.2	−22.2	−57.7	0.0	− 5.3	24.2	90.4	− 5.0	−41.4	123.1	[a]−13.4	− 4.4	77.5	119.0	−11.1
111		− 1.9	− 5.0	10.6	−21.5	.....	.....	−11.4	−19.7	.....	.....	.....	32.1	56.8	− 5.7	−39.6	88.8	− 3.5	− 8.6	78.7	83.8	64.8
13		−13.2	3.7	− 1.7	−27.0	434.8	−17.1	−12.3	− 7.5	.....	.....	.....	3.8	41.8	− 5.2	−40.6	65.3	− 2.6	− 3.1	80.4	110.3	20.8
109		1.5	−13.4	6.6	−20.0	.....	.....	−14.0	−12.7	−57.7	0.0	−15.0	24.6	28.5	− 5.6	−46.5	41.3	[a]− 7.3	−14.1	59.4	96.0	−10.2
31		−21.5	4.5	− 9.6	−28.6	322.0	−17.1	−15.0	−16.1	−51.5	−33.3	−13.6	− 9.2	75.2	−11.5	−31.3	49.8	[a]− 6.8	−11.0	68.3	62.7	82.0
59		−13.7	− 5.2	5.6	.....	500.0	101.0	−18.3	−10.0	−40.0	−33.3	5.5	3.0	16.6	−10.7	−40.3	50.0	[a]− 7.5	−13.2	89.0	142.0	1.1
51		0.0	3.6	− 1.2	−32.0	306.0	109.2	−25.7	−13.8	−47.2	−28.6	−26.1	− 9.1	13.8	−11.6	−43.8	85.0	−17.0	−15.3	78.7	128.7	− 1.2
71		− 9.4	−25.4	−12.2	−21.2	345.6	83.2	−24.7	−10.3	−55.1	−20.0	−14.3	37.8	14.8	−13.2	−29.1	89.0	−11.1	− 1.0	94.4	129.7	1.8
92	Montana	−37.2	−41.6	− 4.9	−31.4	305.3	73.5	−29.9	−26.1	−56.1	−25.0	−12.5	−15.3	−3.3	− 8.9	−39.8	35.7	−11.9	−22.9	39.0	61.0	−15.3
39		− 1.7	5.4	6.4	−16.4	328.6	22.4	−20.8	−14.4	−51.5	.....	−28.0	−13.1	47.5	− 4.2	−45.5	67.6	− 1.5	−20.0	52.2	84.3	−13.6
94		−22.0	−38.0	.6	−26.0	385.2	196.1	−33.3	−31.0	−33.3	−44.4	−20.0	− 4.0	18.4	−17.8	−26.5	100.0	−12.2	−19.5	44.9	60.4	− 4.3
93		3.4	−24.6	− 5.8	−25.1	246.8	100.4	−31.7	−15.3	−47.7	00.0	−17.4	4.8	−1.7	−25.3	−20.8	51.0	−12.9	−18.7	38.2	53.6	− 7.8
38		.6	− 4.4	− 8.3	−22.9	409.8	28.3	−19.8	− 8.0	−42.4	.....	−13.0	13.8	50.0	−13.2	−45.3	40.2	− 1.0	2.8	73.4	115.7	− 3.0
73	New York	−12.0	−10.3	− 1.2	−35.4	527.1	96.9	−21.4	−16.4	−47.2	−50.0	−15.8	00.0	10.9	+ 2.5	−40.7	51.1	−22.8	−19.3	91.6	124.8	10.6
105	Ohio	− 1.0	− .7	23.9	−27.6	.....	.....	− 3.2	−17.9	−55.0	00.0	−19.0	−16.8	56.1	− 8.7	−44.3	58.3	−10.7	−14.6	62.1	126.2	−43.0
80	Utah	6.2	−17.1	4.3	−22.5	488.3	32.9	−26.6	−10.6	−37.3	−37.5	−22.7	−12.9	15.4	−28.7	−18.0	56.0	− 4.7	−14.6	38.4	58.0	−18.5
72	Washington	− 4.0	−18.5	2.4	−22.7	241.4	55.7	−16.9	−14.1	−47.4	−50.0	−22.7	13.8	18.4	−17.0	−28.4	117.0	−10.0	− 5.7	75.2	67.3	200.0
60		−14.8	.7	4.6	−22.1	206.0	66.2	−25.4	−15.2	−40.0	−44.4	−20.0	29.0	2.9	+16.4	−30.3	102.7	−12.7	4.0	66.0	94.6	3.4
115	Wisconsin	−13.1	− 3.3	− .6	−23.2	.....	.....	− 6.9	−20.9	.....	.....	.....	14.4	91.7	−18.4	−46.9	104.0	− 7.9	−16.2	66.2	85.9	12.7
37		6.9	−12.1	−12.1	−31.5	567.8	84.2	−18.9	− 8.3	−37.3	.....	−16.6	21.7	63.6	+ 6.2	−32.3	119.1	−12.7	−11.6	105.1	127.0	52.5
22		−29.7	4.6	−17.9	−50.1	417.5	−49.5	−32.5	−38.4	−61.8	.....	−40.0	−36.4	12.8	− 9.5	−51.7	26.4	−23.0	−38.3	21.1	55.6	−35.2
112		00.0	− 8.8	5.7	−27.1	.....	.....	−16.2	−17.1	.....	.....	.....	58.8	8.2	− 5.8	−38.3	88.4	− 9.2	− 8.5	122.5	161.7	34.9
33		15.5	− 5.1	− 8.8	−36.3	330.0	82.0	−22.0	−18.1	.....	.....	.....	− 3.8	68.1	−14.7	−45.5	75.7	[a]− 7.7	−18.0	75.3	112.0	6.7
106		2.8	− 9.3	6.6	−16.8	.....	.....	−16.6	−17.3	−55.5	−14.3	−14.3	8.3	50.0	−10.7	−40.0	43.5	[a]− .7	−13.7	89.0	127.0	1.6
35		− 8.8	−10.8	− 7.7	−37.2	566.0	52.9	−29.1	−12.7	−54.5	.....	−20.0	1.0	64.3	00.0	−32.7	110.1	[a]−10.8	−12.0	88.3	123.0	12.6
7		− 6.9	− 7.0	− .5	−32.2	395.0	78.7	−14.8	− 7.5	−47.9	.....	−11.1	− 1.1	17.5	− 5.0	−26.5	75.7	−13.3	−14.0	57.3	64.8	42.4

84		− 8.7	− 5.8	− 2.7	−26.4	567.6	88.4	−20.4	−13.1	−44.4	00.0	−21.7	40.9	32.0	− 5.9	−26.4	182.5	−17.5	− 8.0	89.6	125.5	10.6
81		− 3.9	−10.3	1.0	−28.2	488.0	91.4	−29.1	−16.8	−55.9	20.0	−10.5	1.7	66.7	− 6.5	−34.6	40.7	−14.5	−11.2	79.6	105.1	20.3
32		−15.1	− 3.0	−18.6	−33.4	672.0	−23.0	−23.9	−14.6	−58.6	.....	− 9.1	4.1	85.0	− 3.7	−38.6	96.2	a− 9.4	−12.1	83.0	111.1	18.6
55		−11.2	−15.8	.1	−42.6	.....	97.3	−21.2	− 9.2	.....	.....	.....	24.5	23.6	−12.4	−37.0	80.0	−15.1	−15.1	86.8	129.5	4.5
12		−13.4	− 4.6	−10.0	−33.3	560.0	− 8.3	−19.9	−10.4	−51.4	.....	− 8.3	8.0	57.0	00.0	−31.0	84.5	a−10.8	−13.5	53.3	81.0	1.0
137		−10.8	6.8	− 6.3	−32.0	.....	.....	−14.8	− 2.4	−46.6	−12.5	−23.5	51.4	41.5	− 8.4	−47.4	129.1	−20.1	−14.2	112.7	175.6	− 5.7
	Average.....	− 7.7	− 8.4	− 1.6	−28.0	400.0	71.0	−20.7	−12.7	−48.2	−22.3	−17.6	9.0	34.3	− 8.5	−37.0	78.7	−10.2	−12.0	72.5	104.0	13.0

a The factor 89 was used in converting the malt analyses to basis of original barley.

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